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Influence of Forest Cutting and Mountain Farming on some Vegetation, Surface Soil and Surface Runoff Characteristics 1/

by

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INFLUENCE OF FOREST CUTTING AND MOUNTAIN FARMING ON SOME VEGETATION, SURFACE SOIL AND SURFACE RUNOFF CHARACTERISTICS[1/]

by

Robert E. Dils[2/]

PURPOSE AND SCOPE

With the increasing demands made on our water supplies within the past few decades has come the realization that fundamental research concerning this basic natural resource is woefully lacking. Because the water resource is so closely linked with climate, it was the consensus of opinion for many centuries that man could alter it no more than he could the weather. This is not entirely true, for, in addition to climate, the available water supplies may be affected by the vegetation and soil factors. Through his use of the land, man exerts a very significant influence on both the vegetation and the soil. As a result, he also modifies the water resource, but the nature and extent of this modification has been a subject of much speculation and controversy.

Because of the lack of hydrologic data, it has been impossible in the past to establish a scientific basis for the management of water as a natural resource. Currently, an increasing demand for such information is being made by many public and private interests. Industry requires a dependable supply of clean water. Municipalities demand an adequate, pure water supply. Many public and civic agencies require information for flood control programs and power projects. The recreation and tourist trades lean heavily upon the nation's water resource. Fish and wildlife interests are dependent upon clear, cool streams for the production of fish and game.

1/ This paper is a portion of a dissertation submitted to the Graduate School in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Soil Science at Michigan State College, East Lansing, Michigan.

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In recent years, many ambitious projects have been inaugurated; new factories have been built, cities have doubled their facilities for supplying water to an increasing population, sports and recreation areas have been developed--all at tremendous expense and all making tremendous demands on the local water resources. If the water supply is found to be adequate, clean and pure, such ventures prosper. Unfortunately, many of these efforts have been hampered by muddy streams and unexpected stream behavior. When these occur, the land-use pattern of the watershed in question is immediately examined in order to locate the source of the difficulty. Frequently, the watershed will not be entirely in natural forest, but will show a mixed pattern of usage. Small areas may be farmed, grazed or logged. This immediately occasions much heated controversy as to just which area is the cause of the trouble. When mountain farming is one of the factors which appears in a mixed land-use pattern, the decreased value of the development often has been attributed primarily to this practice. Just how harmful the cultivation of small patches of steep land may be has been the subject of much speculation.

Thousands of acres of steep forest land have been cleared for use as cropland or pasture in the Southern Appalachians. To farm such land successfully requires great skill and care. Many authorities claim that much of it should never be farmed at all. It is common knowledge that individual farmers may "wear out" many such mountain farms in a lifetime.

It is the intent of this study to determine the effects of clearing and cultivating steep forested slopes on certain surface runoff characteristics as well as to study some of the resultant biologic and edaphic changes in the watershed.

Numerous studies have been made on cultivated and forested watersheds and indirect comparisons made therefrom. To the writer's knowledge, however, there has been no report in which a forested watershed has been calibrated, clear cut and cultivated and a direct comparison made.

In this study, carried out on the Little Hurricane Watershed on the Coweeta Hydrologic Laboratory in Macon County, North Carolina, the forested watershed was calibrated from 1934 to 1940. In 1940 the area was clear cut and from 1941 to date has been subjected to mountain farming typical of the Southern Appalachian region. As nearly as possible the land has been treated as though a mountain family lived near the stream and tended the area to make its livelihood.

If the effects of clearing steep forest land on the hydrologic behavior of a small watershed can be adequately determined, it should serve as a guide to the land-use questions on larger drainages and basins.

PAST WORK

Numerous investigations have been undertaken in many localities throughout the country for the purpose of measuring runoff and erosion. Many of these studies, however, have been confined to cultivated areas and others have been made on a small-plot or lysimeter scale. The literature

has become so voluminous that no attempt is made here to review it all. Instead, only selected representative projects which provide a particularly pertinent background to the present study will be cited.

Since 1930 the Soil Conservation Service, United States Department of Agriculture, has established 19 soil conservation experiment stations including numerous cooperative projects with state agricultural experiment stations. Similarly, the Forest Service, United States Department of Agriculture, maintains 14 stations where research in watershed management is currently being conducted. In addition, at least nine other watershed research centers are conducting studies under the jurisdiction of other federal and state agencies including the Corps of Engineers in the Department of the Army, the Weather Bureau in the Department of Commerce, the Geological Survey in the Department of the Interior, the Tennessee Valley Authority, and the New York and Michigan State Departments of Conservation.

Stations at Statesville, North Carolina (4), and Watkinsville, Georgia (27), both on the Piedmont, are engaged in cropping and erosion control measures, and measure runoff from small plots, lysimeters, and field watersheds. A comparison of land use practices at the former station indicates decreasing soil losses in the following order: fallow, continuous cotton, rotation (cotton and corn with winter cover crops), grass, woods burned annually, and unburned woods.

In surface runoff the trends are the same except that the burned woods area yields a higher percent of precipitation appearing as surface runoff than does the grass area. In the case of the fallow area, over 17-1/2 percent of the precipitation appears as surface runoff, as compared with 0.7 percent for the unburned woods.

The first experimental watershed project of the Soil Conservation Service was established near Coshocton, Ohio, in the Muskingum Watershed Conservancy District (20, 27). Intensive studies are being made there on the effects of land use and erosion-control practices on the conservation of soil and moisture and on flood flows for 44 complete watersheds supporting various cover types. These watersheds range in size from three to 4,600 acres. An analysis of soil-water relationships on four small watersheds at Coshocton was made by Dreibelbis and Post (10) in 1941. A comparison among a wooded, pastured and two cultivated watersheds all on similar soils showed a much lower volume of surface runoff for the wooded area. On the wooded watershed only 0.11 inch or 0.2 percent of the precipitation ran off compared with 0.60 inch and 1.4 percent for the pastured area and 6.35 inches or 15.0 percent runoff for one of the cultivated areas.

A 250-acre experimental tract near Zanesville, Ohio, including three gaged watersheds, was established in 1933 to study the effect of land use on runoff and erosion. Included in this study is a 2.23-acre wooded watershed. For the 5-year period from 1934-1938, Borst and Woodburn (7) noted the average soil loss from this watershed as 0.017 tons per acre per year. The average annual runoff was noted as 0.1246 inches, which amounts to approximately 0.34 percent of the average annual precipitation.

Near LaCrosse, Wisconsin (14) a 160-acre tract contains three gaged watersheds: a pasture cleared of timber, a grazed hardwood forest and a

typical ungrazed woodlot. An analysis of eight intense storms occurring in 1935 indicated that about 8-1/2 and 3 percent of the precipitation appeared as surface runoff on the timbered-grazed and cleared-grazed watersheds respectively, while on the ungrazed wooded area runoff occurred only twice and then in quantities so small as to be insignificant. The same trends were indicated for soil losses from the watersheds.

An experimental watershed project for the Blacklands region has been established on the Brazos Drainage Basin near Waco, Texas (27), where erosion, land use, hydrologic and soil data are being studied on thirty watersheds. Included in these studies are several wooded plots. Analysis of soil losses and surface runoff indicate similar results to those obtained at Statesville, N. C. Plots on virgin woodlot yielded only 0.122 percent surface runoff and 0.002 tons per acre soil loss compared with nearly 30 and 10 percent surface runoff and 65 and 23 tons per acre per year soil loss for fallow and continuous cotton plots respectively.

A project designed to study the effects of land use and cultural practices on surface runoff was established in 1940 jointly by the Soil Conservation Service and the Purdue University Agricultural Experiment Station at Lafayette, Indiana (3). Included in the twenty gaged drainage areas are two wooded watersheds. Up to 1949, however, no treatment of the wooded watersheds had been attempted.

A similar study involving two small agricultural watersheds and one wooded watershed was initiated in 1940 by the Soil Conservation Service in cooperation with the Michigan State College Agricultural Experiment Station near East Lansing, Michigan (12, 22). This project is unique in that the majority of the installations on the two cultivated watersheds are designed to record the results directly on one master recorder and switch panel. The primary objective of this installation is to study the hydrology of farm lands under winter conditions of snow-cover and frozen soil. Results of the investigations to date indicate a marked difference in soil losses between the wooded watershed and the two agricultural watersheds. Total soil losses from the wooded watershed for a 10-year period amounted to only 64 pounds as compared with many tons from the two cultivated areas. Similar differences in surface runoff were noted except under conditions of frozen ground and snow cover. A commercial clear-cut treatment was applied to the wooded watershed in 1951; however, results of this treatment will not be available for at least 5 years.

Experimental watershed studies by the Forest Service, United States Department of Agriculture, are being conducted at six of the Forest Experiment Stations: Southeastern, California, Southwestern, Rocky Mountain, Intermountain, and Northeastern (27).

At the Southeastern Station, hydrologic studies are being made at the Calhoun Experimental Forest near Union, South Carolina, and at the Coweeta Hydrologic Laboratory near Franklin, North Carolina. At the Coweeta station (16, 25), in addition to the study covered herein, research projects include the determination of the effects of the following treatments upon water yield and water quality: (a) permanent complete removal of all major vegetation, (b) temporary complete removal of all major vegetation, (c) removal of riparian vegetation, (d) local logging practices, (e) woodland grazing, (f) removal of understory vegetation (laurel and rhododendron), (g) temporary defoliation by gas, and (h) forest fires.

The results of investigations being conducted at Coweeta are: (a) cutting all trees on a steep, heavily forested watershed and annually cutting back the sprouts (with no removal of wood products and no disturbance to soil) increases water yields by 17 area inches annually; (b) similar cutting, but with sprouts allowed to grow back, increases water yield approximately 17 inches and this increase becomes progressively less as the coppice stand grows older; (c) cutting streambank vegetation tends to eliminate diurnal fluctuations in stream flow; (d) local logging practices, particularly poorly located and constructed logging roads, effect a marked increase in erosion and stream turbidity; (e) woodland grazing brings about a marked increase in overland storm runoff and erosion and shows that the cattle grazed on the watershed fail to thrive (17); (f) the removal of an understory of laurel and rhododendron effects an increase in water yield of approximately 3 area inches per year; (g) preliminary observations indicate that temporary defoliation of vegetation by gas may be used as an emergency measure in extreme drought periods to reduce transpiration and thus increase water yields.

The major work center for the California Forest and Range Experiment Station is the San Dimas Experimental Forest, near Los Angeles. Projects are under way here to study the disposition of rainfall as influenced by watershed conditions, including vegetation, soils, geology and topography; and to develop methods of watershed management, including the treatment of areas denuded by fire, to assure maximum yield of usable water and satisfactory regulation of flood runoff and erosion. Installations include 17 watersheds, 18 experimental plots and 26 large lysimeters.

Forest influences and watershed management investigations at the Southwestern Forest and Range Experiment Station are carried out on the Sierra Ancha Experimental Forest near Globe, Arizona. Work projects there are designed to determine the influence of vegetation (forest, evergreen shrub, and range) on stream flow, water uses, water losses, erosion and sediment production. Gaged watersheds, plots, and natural lysimeters are utilized. In addition to the Sierra Ancha Experimental Forest, experimental plots are located in representative areas throughout the Salt River Watershed. Plot studies on range land on the Sierra Ancha station demonstrated that ungrazed range land with good plant cover produced higher water yields and much lower soil losses than overgrazed range with poor ground cover (26).

Hydrologic investigations of the Rocky Mountain Forest and Range Experiment Station are carried out at the Fraser Experimental Forest near Grand Lake, Colorado; the Manitou Experimental Forest near Colorado Springs, Colorado; and at the Western Slope Research Center near Delta, Colorado. At the Manitou station, studies are being made on the influence of grazing, timber cutting, and revegetation of depleted watershed lands upon water supplies and more particularly upon erosion and sedimentation. Experiments at the Fraser Experimental Forest are designed to show the influence of lodgepole pine and spruce-fir forests and of the cutting of this timber upon the yield of water largely from stored snow. At the Western Slope Research Center major effort is devoted to the analysis of range and watershed problems for drainage basins of western Colorado. Small grazing and reseeding projects have been established and plans are being drawn for studies of the effects of vegetation and grazing on infiltration and erosion.

At the Intermountain Forest and Range Experiment Station (2, 3) tests are under way to study the effects of forest, brush and herbaceous plant cover in natural, depleted and restored condition on the infiltration, storage, fertility, biology and stability of forest and range land soils; to determine land use practices for stabilizing eroding watershed soils and for maintaining soil stability under the impact of grazing, logging and other wildland uses. Studies are being conducted on coarse, granitic soils of southwest Idaho; various soils on steep slopes of the Wasatch Mountains in northern Utah; and on heavy limestone soils on the Wasatch Plateau in central Utah.

A surface infiltration study made on the Uinta National Forest in Utah in 1951 indicates that infiltration rates averaged from 5 to 50 percent lower on grazed sites than on ungrazed areas. Storm runoff from the grazed plots ranged from 50 to 100 percent more than on the ungrazed areas, and soil losses on the grazed plots averaged six to eight times more than on ungrazed areas (28).

At the Northeastern Forest Experiment Station, a study was initiated in November, 1948 on the Lehigh-Delaware Experimental Forest (23) of about 1800 acres to determine the influence of the present scrub-oak cover on runoff. After a period of calibration it is planned to convert the cover from scrub-oak to a better forest type by forest management and protection measures and to evaluate the effect of these changes in cover on runoff and ground water.

The earliest hydrologic investigation in this country concerned with the influence of forests on streamflow and runoff was initiated in 1909 by the United States Forest Service and the United States Weather Bureau at Wagon Wheel Gap, Colorado. Bates and Henry (5) reported in 1927 that the cutting of forest cover increased the total annual water yield, increased water yield from snow and produced increased erosion. They further indicated that the results were blurred by such conditions as porous soils, thin original cover and prolific sprouting of aspen.

One of the earliest investigations was that initiated by Ramser in 1917 near Jackson, Tennessee. He worked with six watersheds varying in size from 1.25 to 112 acres, five of which were in mixed land use and contained forest cover varying from 14 to 55 percent. Ramser reported in 1927 (19) that forest cover has a decided influence in reducing the rate of runoff from a watershed except when antecedent rainfall has been high, in which case the influence is slight.

In 1932 a study was started by the Geological Survey, United States Department of Interior, in cooperation with the State of New York Conservation Department to determine the influence of reforestation on stream flow in state forests in central New York. Submarginal lands were purchased and planted to coniferous tree species. Ayer (1) reported in 1949 that up to that time practically no significant change in runoff had been effected.

One of the most recent reports is that of the White Hollow Watershed in Union County, Tennessee published by the Tennessee Valley Authority in 1951 (24). The 1715-acre White Hollow Watershed was set aside for watershed studies in 1936. Following acquisition, watershed management included extensive erosion-control operations and tree planting. The study shows the following changes in surface runoff and other hydrologic characteristics as a result of

15 years of improvement and management: (a) The improvement in forest cover which occurred resulted in greater watershed protection without measurable decrease in water yield. (b) There was no shift in the seasonal runoff pattern as a result of land-use changes. (c) No measurable change took place in the total quantity of evapo-transpiration plus other losses. Apparently, since a greater density of vegetal cover must be supported by greater water use through transpiration, balancing factors were in operation. (d) Peak discharges during the summer season were markedly reduced. Reductions in winter peak discharge rates were not appreciable. (e) The greater part of the peak discharge reduction occurred in the first two or three years of investigations, smaller reductions continuing after that time. (f) Modification of summer peak discharges were so great that the frequency of peaks during the latter years was much less than during the earlier years. (g) The time distribution of surface runoff was materially changed. Surface runoff discharge was prolonged to produce a more sustained flow. (h) Comparison of sediment records based upon manually collected samples during early years with records obtained during the past year (1950) by means of an automatic sampler shows clearly that there has been a very material reduction in sediment load during the 15-year period of observations.

It is apparent, after a review of the literature, that a direct comparison of the results of this study with any previously reported is virtually impossible. Many studies have demonstrated that watersheds or plots with undisturbed forest cover yield less surface runoff and produces less soil loss than grazed or burned forests, pastures and croplands. In few cases, however, have attempts been made to show changes in surface runoff except in terms of total surface runoff expressed as a percent of the precipitation.

The study made in this report is unique in that the watershed was calibrated under forest conditions, the forest cover was removed and land use practices then applied. In addition, an adjacent watershed with similar characteristics was maintained in continuous forest cover, thus providing a further control. Consequently, an opportunity was provided to study more detailed changes in surface runoff.

THE COWEETA HYDROLOGIC LABORATORY

With the recognition of the need for additional research in watershed management came the realization also that the selection of sites for such research would be complicated and difficult. Foresters, hydrologists and engineers contributed rigid specifications which had to be fulfilled if the findings were to be valid and of more than local significance.

One area which met every important requirement was a 5,600-acre tract in the Nantahala Mountains of western North Carolina. This tract, established in 1933 by the United States Forest Service, is now internationally known as the Coweeta Hydrologic Laboratory. Several factors combine to make the area ideal as a natural laboratory suitable for fundamental hydrologic research. Rainfall is high, averaging 72 inches per year, and is rather uniformly distributed throughout the year. Because of the frequency of storms and the uniformity of the storm pattern, it is possible to obtain

valid results in much shorter time than in an area of less precipitation. Approximately 98 percent of the precipitation occurs as rain, so there is little snow to complicate the studies.

Topographically, this particular section is also ideal in that its steep slopes and sharp ridges form natural boundaries for the many small drainage basins--each an independent hydrologic unit--necessary for research of this type. Elevations vary from 2,200 to 5,200 feet within the boundaries of the station.

Although over half of the Coweeta area was cut over 25 years before the government acquired ownership, land use practices have altered the character of the forest itself very little. A dense mixed-hardwood forest, typical of much of eastern United States, is predominant at Coweeta. The cut-over lands support second-growth forest and the remainder of the land is in old growth. Chestnut was formerly the major species but has been wiped out by the blight. The largest part of the forest is now in oak-hickory. Another 15 percent is in cove hardwoods: yellow-poplar and northern red oak, intermixed with hemlock along the streams. Sugar maple, yellow birch, beech and pitch pine occur occasionally at the higher elevations.

Because of the similarity of this area to many other parts of the country and because of the favorable pattern of precipitation, data derived from studies on the Coweeta tract can be applied elsewhere. Consequently, research conducted here in water behavior and management has national as well as local significance.

THE LITTLE HURRICANE WATERSHED

The Little Hurricane Watershed, designated as drainage No. 3, is located in the Coweeta Hydrologic Laboratory, Macon County, North Carolina. Its location within the Coweeta area is shown in figure 1 along with the control watershed, No. 2. The waters of the Little Hurricane Branch flow into Shope Creek and thence into Coweeta Creek, which is a tributary of the Little Tennessee River. Figure 2 shows an over all view and map of the study watershed. Its aspect or exposure is essentially southeast.

Land Use History

In 1835 a hurricane is reported to have levelled all the timber in the Little Hurricane and the Hurricane drainage adjacent to it; hence the names of the watersheds. Prior to 1857 white settlers pushing into this region grazed the drainage area to some extent. As the Indians before them had done, the settlers practices semi-annual burning of the woods in order to improve the quality of the grazing. In 1857 the second-growth timber on the lower ten acres of the watershed was cleared for farming and the area was cultivated until 1887. This included nearly all of the areas which are now the lower pasture and abandoned cornfield. The yields became so low that the fields were then used only for grazing until 1900.

In 1901 the area was included in the land purchased by the Nantahala Company, a land speculation group. From 1901 until 1940 "third-growth" timber, largely of the oak-chestnut and cove hardwood types re-established

Figure 1.--Individual drainage areas at Coweeta.

itself. By 1934 the dominant trees were 18-20 inches in diameter. The chestnut, however, had dropped out because of the blight.

Only the best quality oak, chestnut and yellow-poplar was logged from the second growth forest adjoining the old field in 1914. The remaining trees were left unharmed except for the damage occasioned by the logging.

The U. S. Forest Service acquired the area in 1923 and it became a part of the Nantahala National Forest. In 1934 the drainage was included in the area set aside as the Coweeta Experimental Forest. This name was officially changed to the Coweeta Hydrologic Laboratory in 1949.

After a period of standardization or calibration starting in 1934, the watershed was clear cut in 1940 preparatory to the "mountain farming" treatment. Figure 3 shows clearing operations by CCC enrollees during the winter of that year.

Figure 2.--The Little Hurricane watershed comprises 22.79 acres.

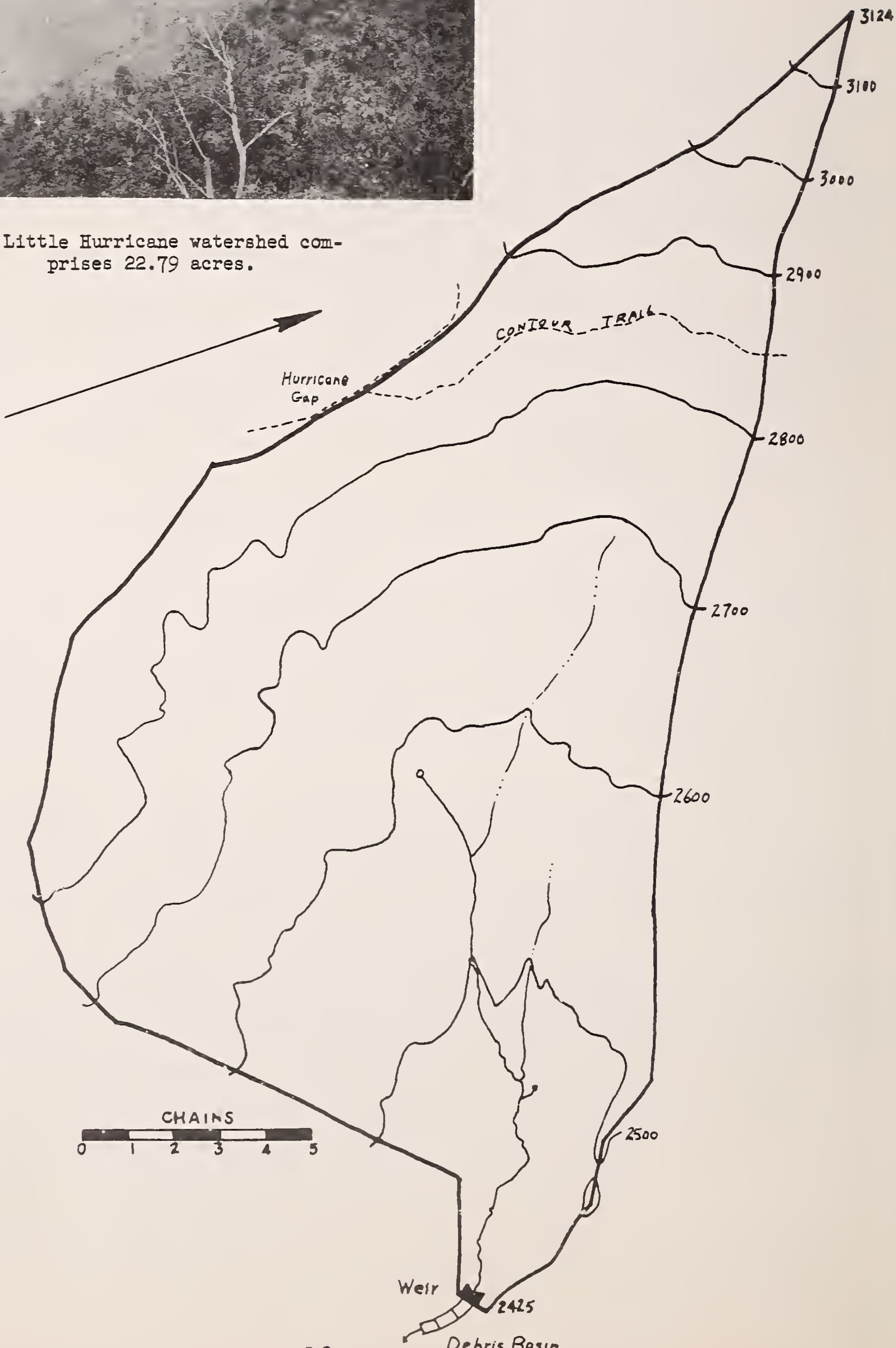

Figure 3.--Clearing operations by CCC enrollees, 1939-1940.

Geology and Physiography

The Little Hurricane Watershed lies in the Blue Ridge province of the Southern Appalachians. The underlying rock is the Archean Carolina gneiss and schist. The thickness of this formation, which was enormous, was greatly increased by complex folding. As a result of folding and the absence of open faults and fractures, there is little likelihood that continuous channels exist to permit the subterranean escape of water through the rock.

The parent material weathers to form a relatively deep soil mantle with bare outcrops of rock appearing only on the steeper slopes at high elevations. Two small outcrops occurring on the upper slopes of the drainage are shown in figure 2.

The topography of the area is steep and rugged. The mean sea level elevations range from 2,425 feet at the base of weir to 3,124 feet at the top of the watershed. The distance from the base to the top is about one-third mile. The land slopes are quite steep with north-south averages 46 percent and east-west averages 58 percent. The mean slope for the watershed is 51 percent and the range is from 10 percent near the bottom to nearly 80 percent at the head of the drainage.

The drainage pattern of the Little Hurricane Branch is dendritic, the stream channel is V-shaped and the slopes are concave, all indicating the youthful stage of the stream. The permanent stream channel is 436 feet long with a drop of 65 feet. The average stream gradient is 14.9 percent.

The ground water table is only slightly less steep than the general slope of the land surface, and at four observation wells ranges from 8 to 16 feet below the soil surface.

Climate[3/]

The climate of the Coweeta area is characterized by moderate temperatures and abundant rainfall. The mean annual temperature is 55°F. and the normal frost-free season extends from April 17 to October 23, a period of 189 days. The average temperature during the growing season is 65°F. Recordings of 90°F. are rare, and summer nights are cool with minimums averaging 58°F. The three coldest months, December, January and February, average 39°F. Periods of cold weather with temperatures below 20°F. are short in duration. The highest and lowest recorded temperatures are 94°F. and -15°F. respectively.

The average annual rainfall over the Coweeta Hydrologic Laboratory is 80 inches and is well distributed throughout the year. For the past 15 years, precipitation has averaged 3.2 inches in October, the driest month, and 7.2 inches in March, the wettest month. The greatest amount of rainfall is received in the southwest portion of the area and the least in the northeast corner. The difference between these two zones is about 20 inches a year.

The average monthly evaporation, measured by a standard U. S. Weather Bureau evaporation pan, varies from 0.98 inches in December to 4.10 inches in May. The average total evaporation for the year is 33.56 inches, or 2.80 inches per month.

Soils

The soils on the watershed are derived from Archean granite gneiss and schist. The parent rocks weather to form a relatively deep soil mantle. A colluvial fill which is more than 20 feet thick occurs on the lower portion of the drainage. On the upper slopes the soil mantle ranges from 5-10 feet in thickness. Two rock outcrops and evidences of an old landslide are present. The lower pasture land shows the effects of former cultivation more noticeably than the areas recently cropped.

Except for the colluvial fill at the base of the watershed, the soils are classified as Porters loam (9).[4/] In the colluvial fill they are Por-

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3/ All climatic values given here are based on 15 years record at weather station #1 (Headquarters area) Coweeta Hydrologic Laboratory.

4/ The entire watershed was mapped by Devereux et al in 1929 as Porters stony loam. After the examination of numerous soil profiles throughout the area and more recent descriptions of the Porters stony loam, Porters loam, and Porters loam colluvial phase, it is believed that the above classification is more nearly correct.

ters loam colluvial phase. The surface soil of Porters loam ranges from 6 to 12 inches in depth and consists of mellow and friable brown loam. The subsoil, to a depth of 20-28 inches, is a red to reddish-brown, friable and crumbly clay-loam. Below this is a reddish-brown mixture of clay loam and disintegrated rock.

Porters loam colluvial phase, is similar in color to typical Porters loam but is much deeper and in some places practically no difference exists between the surface soil and the subsoil. This soil contains a fairly high content of rock fragments which have rolled down from the mountain sides.

According to Devereux et al (9) Porters loam is considered as one of the better agricultural soils of the county. If it occupied more favorable relief, probably all of it would be cultivated, but under existing conditions only a small part is in such use. The principal crop is corn, and yields range from 15 to 40 bushels per acre. Cabbage, potatoes, snap beans, and pumpkins do well also. Porters loam is one of the good pasture-grass soils of western North Carolina. Soils of the colluvial phase are used for the production of corn, cabbage and potatoes, and the yields are about the same as those obtained on typical Porters loam.

Vegetation

Previous to clearing, the primary forest vegetation consisted of second-growth forest of the oak-chestnut type, with cove-hardwood and yellow pine-hardwood types on smaller areas. The scale for the merchantable timber cut on ten acres below the contour trail during clear cutting operations in 1940 is given below (Scribner Decimal C rule with allowance for defect):

Species	Board feet
Pitch pine	2,040
Yellow-poplar	7,750
Black oak	2,310
White oak	420
Chestnut	250
Basswood	590
Red oak	560
Total (141 logs)	13,920

HISTORY OF THE EXPERIMENT

Instrumentation - Installations

Precipitation.--Precipitation or recharge to the watershed is measured by three standard rain gages, numbers 16, 20, and 67. Gages 16 and 20 have been in operation continuously since July 4, 1934. Gage 67 was installed on June 9, 1940 and has been in continuous operation since that date. Previous to the installation of gage 67, measurements from standard rain gage 21 were also applied to the area.

Until June 9, 1940, rainfall intensities were measured by recording rain gage 1, located on the adjacent drainage area No. 7. Gage 10 has been used since its installation on June 9, 1940. Recording rain gage 10 and standard rain gage 67 are located adjacent to each other in order to provide a check against the accuracy of the former.

Charts are changed at least once a week on the recording rain gage and it is completely serviced and checked at least once each year. The standard rain gages are read following each storm or as nearly so as possible. Standard rain gage data are summarized and tabulated by months, hydrologic seasons, calendar years and hydrologic years.

To compute the total precipitation of the watershed, the Horton-Theissen Means method (15) of weighting precipitation is used. Figure 4 shows the geometric division of the watershed for these calculations, as well as the location of the different installations.

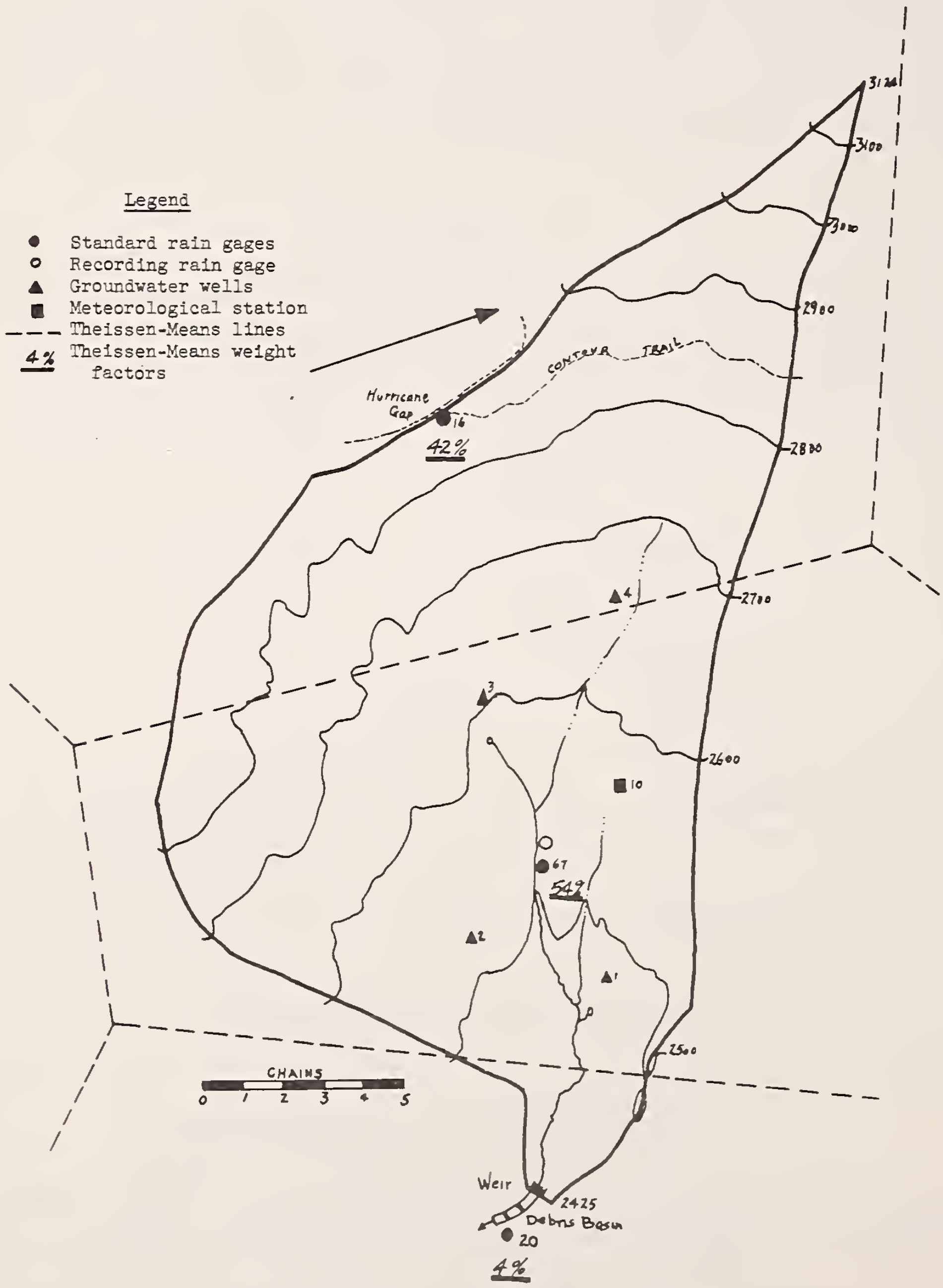


Figure 4.--Installations for measuring water cycle components on the Little Hurricane drainage area.

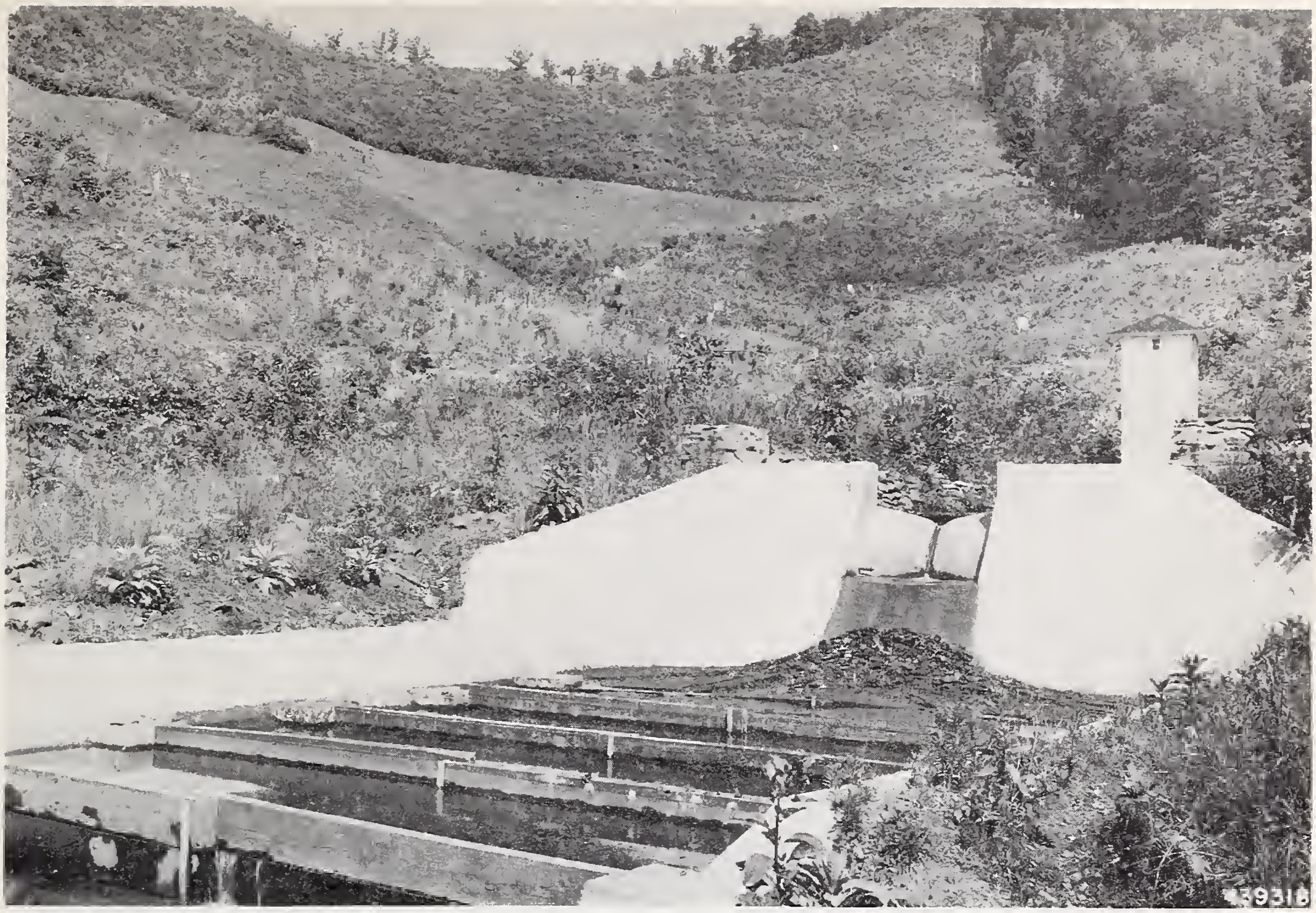


Figure 5.--Columbus deep-notch control for measuring stream flow. At right of weir is the gage house; below is the catchment basin for collecting sediment.

Precipitation intensities are computed from the recording rain gage charts. These data are then tabulated on precipitation intensity records and corrected to agree with the reading of the standard rain gage located adjacent to it. Since the area of the watershed is only approximately 23 acres, a single recording rain gage is used for intensity determinations.

<u>Stream flow</u>.--To measure the discharge from the watershed a 90-degree V-notch weir with a continuous water stage recorder, was installed on July 5, 1934. In order to measure a wider range in stream flow and to accommodate greater debris loads, anticipated as a result of the watershed treatment, the 90-degree V-notch control was replaced with a Columbus CIA deep-notch control in December 1939. Figure 5 pictures the latter stream control. In addition, a concrete stilling well was installed.

To convert the stream-flow data into usable form, the head and time readings are taken from the water level charts and then converted into volume values, i.e., cubic feet per second (c.f.s.) and cubic feet per second per square mile (c.s.m.). For special storm studies, inches per hour is used as well. Volume data are, as in the case of precipitation data, summarized by days, months, hydrologic seasons and years as well as by individual storms. For special storm studies, volume values are plotted over time to give the storm hydrographs.

Water stage recorders are completely serviced and overhauled at least once per year. Recorder charts are changed at least once per week and more frequently when major storms occur.

Soil losses.--In August of 1941 the concrete debris basin shown in figure 5 was constructed to measure soil losses from the watershed. The design of the basin was based upon Stokes Law of the settling velocity of particles in a liquid. The installation consists of three individual basins each with five baffles. The basin obviously catches all but the finest materials as evidenced by the absence of sediment in the stream channel below the installation.

The debris basin is cleaned each spring if required or more frequently in seasons with major storms producing heavy soil losses. Prior to the installation of the debris basin, estimates of soil losses were made from samples taken from the silting basin.

Ground water.--To study fluctuations in the ground water surface, four wells were installed during the summer of 1941. Daily measurements of the water elevations in the wells were made until November 1, 1942. At that time water stage recorders were installed on wells 1 and 2. Weekly measurements of the water levels in wells 3 and 4 were made until April 24, 1944 when, due to a shortage of funds and labor, water level readings in these two wells were discontinued.

Because of the restricted scope of this study no attempt was made to include ground water studies.

Period of Standardization, 1934-1939

On July 5, 1934, a 90-degree V-notch stream control was put into operation along with two standard rain gages (No. 16 and No. 20). A recording rain gage of the float type (No. 1) and another standard rain gage (No. 21) were installed on October 18, 1934 in the adjoining drainage (Hurricane or area No. 7).

On August 3, 1939 the V-notch weir was removed and on December 20, 1939 a modified Columbus type 1-A deep-notch stream control was installed in order to measure a greater range of flows and to accommodate greater debris loads.

The maximum rate of runoff measured before clearing was 110 cubic feet per second per square mile following a rain of 4.67 inches in November of 1938. The maximum intensity of this rain was 2.12 inches per hour.

Before clearing, the rate of sediment movement, based on accumulation in the weir pond, was 9.6 pounds per day.

Clearing Operations, 1940

Logging and clearing operations were started in November, 1939 and were completed in July, 1940. The merchantable timber on the area below the contour trail was sold to a local firm and logged to simulate local practices. The balance of the watershed was cleared by CCC enrollees. On the lower portion, stumps over 16 inches in diameter were pulled and the brush was piled and burned around the larger stumps which remained. On the upper portion the trees were cut and the slash scattered over the ground to form a mulch. About two acres of the area about the contour trail was burned over by a forest fire which occurred on July 2, 1940.

Mountain Farming Treatment, 1941-1951

In the spring of 1941 an area of 5.6 acres was plowed and planted to Hickory King corn (fig. 6). The corn was cultivated by hoe during May and June and the crop of about 23 bushels per acre was harvested in November. If the 1942 season Hickory King corn was again planted and yielded

Figure 6.--Plowing cornfield with single-foot or bull-tongue plow for first crop of corn, April 1940.

over 15 bushels per acre. Hog-proof fence was installed around the cornfield during the season. Golden Prolific corn was planted in 1943 and gave slightly less than 15 bushels per acre. The 1943 season was marked by abundant rainfall and intense thunderstorms. The first notable washing of the cornfield occurred during this season. Due to a lack of funds and labor, the cornfield was permitted to grow up into weeds and shrubs during the 1944 and 1945 seasons. Cattle, however, were excluded from the area. In 1946 the cornfield was cleared of weeds and woody vegetation and plowed again. Hybrid U. S. 13 yellow corn was planted. The harvest was 11.6 bushels per acre. In 1947 and 1948 Hickory King corn was again planted and 800 pounds of fertilizer mixture of 4-10-4 and 4-10-6 were applied. The respective yields for the two seasons were 16 and 14.4 bushels per acre. Figure 7 shows harvesting operations in 1948. In 1949

Figure 7.--Harvesting 1948 corn crop. Yield 14.4 bushels per acre.

Hickory King corn was planted and fertilizer applied for a third time. Due to decreased fertility and numerous intense thunderstorms resulting in soil as well as corn washing, the yield for 1949 dropped to 1 bushel per acre. Since yields had decreased to the point where the cultivation of corn was no longer profitable, the area was converted into pasture following the 1949 season. Figure 8 summarizes the corn yields for the 7 years of record.

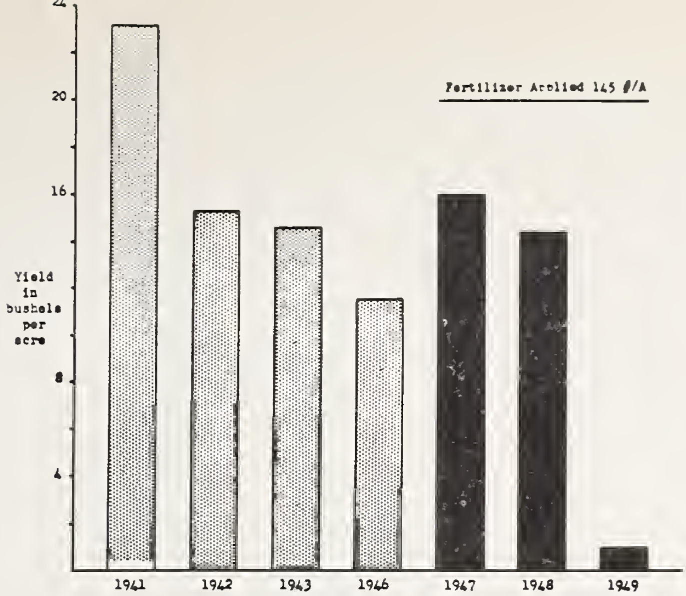


Figure 8.--Summary of corn yields, 1941-1949.

Of the 17 acres outside the cornfield (fig. 9) about 10 acres were too rough or brushy for pasture and were permitted to grow up into coppice forest. One hundred pounds of Cherokee pasture seed mix was sown on the remaining 12 acres in 1942. Competition from trees and shrubs, however, prevented a good catch of grass. Cattle were alternated between this pasture and the adjacent wooded watershed (No. 7). In all there were 336 animal days of grazing on watershed No. 3.

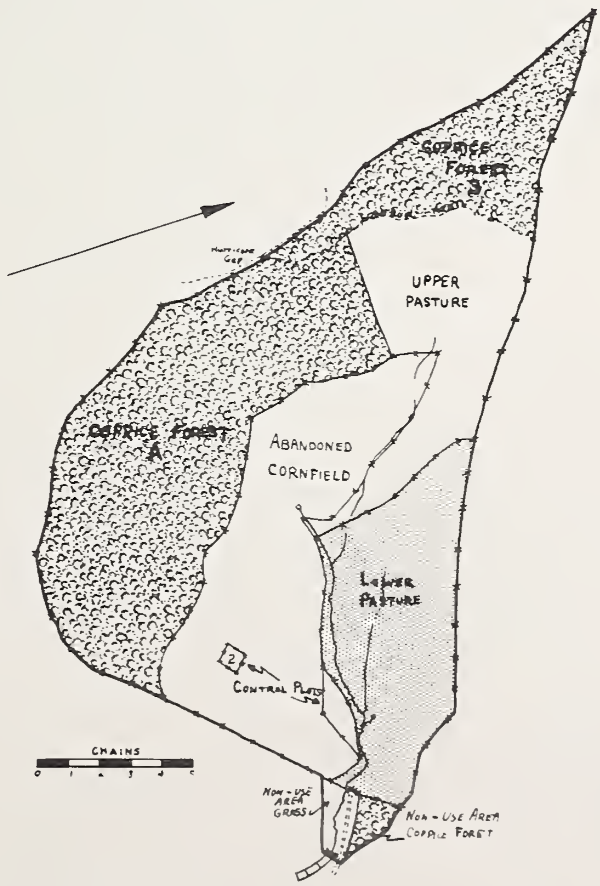


Figure 9.--Map showing the four different types of land use in 1951.

During the 1943 season eight animals were grazed for 67 days. In March 100 pounds of Italian rye grass and red top were sown over the pasture area and in August the sprouts and shrubs below the contour trail were cut back in an attempt to improve the forage. In 1944 a drift fence was built just below and to the right of the recording rain gage to control grazing and to prevent concentration on the lower portion of the pasture. Five head of cattle were alternated between the two portions (designated upper and lower pasture) for a total of 685 animal use days. Nearly all the available forage was consumed in the lower pasture and the soil surface was severely trampled and compacted. During the 1945 season similar grazing use was permitted. In 1946 100 pounds of lespedeza seed were sown over the pastures. The extremely dry weather in August of that year apparently eliminated most of the seedlings established from this planting. The fence between watersheds 3 and 7 was opened and the cattle alternated between the upper pasture of watershed 3 and all of No. 7.

During the 1947 season, cattle were kept continuously on both the upper and lower pastures for a total of 588 days of grazing. In February the woody sprouts on the lower pasture were cut back. An average of four head of cattle grazed continuously on the two pastures in 1948 and were given supplemental feed the last 2 weeks on the area. Similarly, in 1949, four head of cattle were rotated between the upper and lower pastures and were given supplemental feed after August 1.

In 1950 the former cornfield was converted to pasture. The total grazing use in 1950 was 881 animal days. The cattle were periodically rotated between the upper and lower pastures and the abandoned cornfield. During the 1951 season both pastures and the abandoned cornfield were grazed on a rotational grazing system. During August of 1951 the shrubs, weeds, and tree sprouts were cut back, stacked and burned in an effort to improve the pasture conditions.

Soil losses accumulated in the concrete debris basin were measured for the first time on May 28, 1943. Measurements were made thereafter in September 1943, April 1946, April 1947, April 1948, April and July 1949, April 1950, and April 1951. In both 1943 and 1949 numerous intense thunderstorms occurred, necessitating two soil-loss measurements.

The two largest flood flows recorded occurred in 1943 and 1949. On July 30, 1943 a high of 398 c.s.m. was recorded. The maximum flood for the 17-year period occurred on July 10, 1949, when a peak of 1849 c.s.m. was recorded. Figure 10 shows some of the debris carried down by the latter storm. An estimated 76 tons of soil and debris came off the drainage in 30 to 40 minutes during this storm. Figures 10 and 11 indicate the extent of soil displacement during the 1949 season.

During the summer of 1949, surface infiltration studies were started and have been continued to date. Following the harvesting of the 1949 corn crop, two control plots were established and fenced in the cornfield so that vegetative cover changes could be noted.

Figure 10.--Rock deposit in ponding basin, storm of July 10, 1949. Note inlet to stilling well kept clean in order to get record of runoff.

Figure 11.--Soil displacement during the 1949 season.

CHANGES IN SOME BIOLOGIC AND EDAPHIC CHARACTERISTICS OF THE WATERSHED AS A RESULT OF LAND USE

Vegetation Changes

To observe the changes in the vegetal cover on the watershed brought about by forest cutting and mountain farming, a vegetative survey was made in August, 1951. Due to the heterogeneous mixing of the species through the area, no attempt was made to construct a type map. In lieu of a map, the vegetation was observed and identified and its relative abundance was noted according to the different land use elements. Figure 9 indicates the different land uses in 1951.

Coppice forest.--In figure 9 two areas of coppice forest are noted. Coppice forest "A" was cut in 1939-1940 and sprouts have not been cut back. Coppice forest "B" was cut at the same time but sprouts were cut back in 1941. The forest and herbaceous cover of the two areas was so similar in size, density and species composition that they were treated as one. Since a large portion of tree stems were of sprout origin the area was classified as coppice forest.

Except along the ridges, the forest cover was so dense that a ground cover of shrubby and herbaceous vegetation was almost excluded. Along the ridges and in a few openings, greenbrier and wild grape were still abundant. On the slopes, however, these species were much less common, although plant remains indicated that they had been quite abundant there until a few years before. The most common tree species were yellow-poplar, dogwood, sweet hickory, chestnut, red maple, northern red oak, black locust, pitch pine, persimmon, sassafras and black oak. On the ridges pitch pine, white oak and chinquapin were more common and yellow-poplar less abundant than on the lower slopes.

Rhododendron and mountain laurel occurred rather commonly near the ridges and to a lesser degree on the slopes. In the adjacent undisturbed forest areas a moderate understory of these species occurs. Rhododendron and laurel appear to be slow in re-establishing themselves.

The dominant trees were approximately 3 to 3.5 inches in d.b.h. and 12-15 feet in height.

Pastures.--The vegetation of the upper and lower pastures and of the old cornfield is quite similar. Species comprising the present vegetal cover showed no apparent relationship to the vegetative types mapped in 1940. Tree seedlings and sprouts observed in 1951 which were not indicated in the 1940 survey include hawthorn, swamp willow, yellow oak, blackjack oak, green ash, spicebush, yellow birch, black walnut and butternut. The latter two species were probably carried into the area by squirrels or groundhogs. All species observed in 1940, however, were present on the area in 1951.

A much more marked change took place in the shrubby and herbaceous vegetation. Of those species observed in 1940 only nine were found in 1951. On the other hand, a total of thirty-three species were identified

which were not listed as present in 1940. It is significant, too, that many of these invading species, such as yarrow, smartweed, mullein, Canada thistle, nettle and purslane are usually associated with land abuse.

Abandoned cornfield.--As indicated previously, the species composition of the abandoned cornfield is virtually the same as that of the two pastures even though it had been only 2 years since the area was cultivated. The vegetation density of the abandoned cornfield as well as the two pasture areas varied from practically zero on several of the "scald" areas to about 30 to 40 percent ground cover on the best areas. The two control plots indicated in figure 9 were fenced off in 1949 following the harvest of the last corn crop. Cattle have been excluded from these two plots and sprouts have not been cut back. The vegetation here is nearly the same as that of the cornfield in species composition. In the lower plot (No. 1) blackberry and wild strawberry are the two most abundant species. The ground cover in this plot is nearly complete but in spots consists solely of wild strawberry. In the upper plot (No. 2) the same species are represented but the ground cover varies from 65 to 80 percent. It is apparent that in both plots tree species will soon take over. Numerous stems, particularly in the lower plot, are over 6 feet in height.

Trout Habitat

Several studies have been made on the Little Hurricane watershed to show how forest cutting and subsequent mountain farming may change a stream as a trout habitat. Trout are known to be able to withstand a wide range of acidity, alkalinity and carbon dioxide tension. They are, however, quite sensitive to changes in turbidity, stream temperature and siltation.

Turbidity tests comparing the water of the Little Hurricane Branch with that of Bee Branch (a forested watershed) were made from 1946 to 1950. The results of this study indicated that turbidity values for the mountain farm stream were nearly three times as great as those for the forest stream.

Trout are especially sensitive to thermal fluctuations in their environment, particularly when these changes occur near their upper limits of tolerance. During 1948-1949, a stream temperature study was conducted at Coweeta, in which the Little Hurricane Branch was compared with a stream from a forested watershed. Greene (13) reported in 1950 that the weekly maximum temperatures of the farm stream ranged from 9 to 23°F. above those of the forest stream, or an average of 11.5°F. The maximum temperature for the farm stream varied from 65 to as high as 79, whereas the forest stream never exceeded 66, which is considered optimum temperature for brook trout.

Similarly, siltation has been found to be very detrimental to the natural reproduction of trout. The increase sediment load carried by the Little Hurricane Branch following forest cutting and mountain farming is shown in Table 1.

It appears evident then, from the changes in siltation, turbidity and stream temperature on the Little Hurricane Branch that forest cutting and subsequent mountain farming may destroy a stream as a trout habitat.

Edaphic Changes

Many factors, such as climate, vegetation density, type of vegetation, slope, geologic substrata, land use practices and the physical charac-

teristics of the soil combine to determine the stream flow characteristics for a given watershed. The amount of precipitation that goes into stream flow is to a large degree determined by the physical properties of the soil. The characteristics of the plow layer of the soil are strongly influenced by the vegetation it supports. For this reason, any practices which change the nature of the vegetation may in turn bring about changes in the physical characteristics of the surface soil and consequently in stream flow.

One of the most obvious expressions of soil changes is in the degree of soil erosion or in the determination of soil losses from the watershed. Measurements of the soil losses from the watershed have been made since the beginning of the project and are summarized in this section.

Another measure used to determine gross changes in soil characteristics, particularly as they affect water relations, is that of changes in their infiltration rates. Exploratory tests on infiltration were made using the cylinder ring test method in 1949 and 1950 and are summarized in the following pages. During the summer of 1951 a large-scale infiltration study of the entire watershed was commenced. The results of this investigation, however, will not be available for several seasons.

In order to determine more detailed changes in the physical characteristics of the surface soil, soil core and sack samples were collected for analysis. Cylindrical cores 3 inches in diameter by 3 inches long and approximately 1 pint sack samples were collected from the 0-3 and 3-6 inch layers from six sites. Five samples were collected from each of the following sites from both layers: undisturbed forest (from control plots in adjacent watershed, same soil type), coppice forest, upper pasture, lower pasture, abandoned cornfield, and control plots within the old cornfield. The sampling plots were randomly selected from numbered grid cross-sections except from the control plots in both the undisturbed forest and the abandoned cornfield. The latter were stratified at right angles to the contour.

From the sack samples mechanical analyses and organic matter determinations were made. The core samples were used to measure permeability, capillary, noncapillary and total porosity, volume weight, and aggregate analyses. The results of these various determinations are presented in the following pages.

Soil losses.--As indicated previously, soil losses since 1941 have been measured using the specially designed debris basin. Prior to the installation of the debris basin, soil losses were measured from deposits in the silting basin. In making these measurements, the water is allowed to pass over the weir blade before it is diverted into a trough which bypasses the debris basins, thus providing a continuous record of stream discharge. Samples of two hundred cubic centimeters of sediment are taken from each baffle within each of the three debris basins after the sediments have dried. Following volume measurements in each baffle, the debris is removed. The total soil losses are then computed from the dry weight of the samples and from the volume measurements applying to each division of the basin.

The total soil losses measured from the inception of the experiment on July 5, 1934 to the measurement made on April 11, 1951 are summarized in table 1. It is apparent that soil losses have increased tremendously following the treatment of the watershed. The actual increase amounts to over 12 times as much soil loss per acre per year. Before the installation of the debris basin (watershed in forest cover until the winter of 1939-1940) the total soil loss amounted to 1081 pounds per acre or 154 pounds per acre per year. A portion of this amount can be attributed to the treatment, since the debris basin was not installed until nearly two years after the clear cutting of the watershed was started. Since the installation of the debris basin, an average loss of over 1900 pounds or nearly 1 ton per acre per year has been measured. The maximum loss was measured in 1949, when precipitation ranged well above average. For the 93-day period from April 9 to July 11, a total loss of 185,875 pounds, or an average of nearly one ton per day was measured for the entire area.

Table 1.--Summary of soil losses

Period	No. days	Treatment	Total loss, dry weight	Average loss per day	Average loss per acre per year
			Pounds	Pounds	Pounds
7/3/34 to 8/27/41	2557	Forest cover and initial treatment	24,637	9.6	153.7
8/28/41 to 5/4/43	644	Corn, pasture	13,928	21.6	345.7
5/5/43 to 9/8/43	126	Corn, pasture	79,058	627.4	10,043.9
			Average	118.1	1,890.6
9/9/43 to 4/16/46	1185	Fallow, pasture	44,085	37.2	595.5
4/17/46 to 3/28/47	345	Corn, pasture	13,507	39.2	627.5
3/29/47 to 4/13/48	381	Corn, pasture	16,186	42.5	680.0
4/14/48 to 4/8/49	359	Corn, pasture	32,879	91.6	1,466.4
4/9/49 to 7/11/49	93	Corn, pasture	185,875	1,998.6	31,995.1
			Average	210.9	3,377.7
7/12/49 to 4/10/50	272	Pasture	42,330	155.6	2,491.0
4/11/50 to 4/11/51	365	Pasture	21,361	85.5	936.5
			Average	100.0	1,600.8
		Total soil loss 8/28/41 to 4/11/51			449,209 pounds
		Average loss 8/28/41 to 4/11/51			1,933 pounds per acre per year

As indicated previously, an estimated 76 tons of soil and debris came off the watershed in a period of 30 to 40 minutes during the storm of July 10, 1949, when a record peak of 1849 c.s.m. was recorded. Figure 10 indicates the magnitude of soil losses resulting from this storm.

These data indicate that the greatest soil losses were sustained while the cornfield was under cultivation. From September 1941 to September 1943, the average soil loss amounted to nearly 1 ton per acre per year. Following this period, the cornfield was permitted to lie idle until the 1946 season. The pastures, however, were grazed. A decrease to approximately 600 pounds per acre was noted for this period. Soil losses mounted to over 2-1/2 tons per acre per year for the period from 1946 to 1949 when the cornfield was again cultivated. After the 1949 season the cornfield was converted to pasture. Two fenced, ungrazed enclosures were installed as controls (fig. 9). A decrease to 1,600 pounds per acre per year in soil losses was noted from August 1949 to April 1951.

If the losses from the various land-use divisions of the watershed could be analyzed separately, it would undoubtedly be found that by far the greatest percentage of the total loss was contributed by the cornfield and the lower pasture. Evidence indicating this is found in the numerous scalds in the cornfield and the lower pasture where topsoil has been completely removed and the red subsoil exposed.

On several occasions during the 1951 season, storms which produced peak discharges of less than 5 c.s.m. were observed to produce turbid overland flow in the abandoned cornfield and in the lower pasture. In 10 years of field observations during and following storms, overland flow or evidence of overland flow has never been observed in the coppice forest area.

Infiltration.--A surface infiltration study made on the watershed in July, 1949 demonstrated how the small, heavily trampled area of the lower pasture might be the source of a large proportion of the total storm runoff.

To measure the infiltration rate, a steel cylinder 10 inches in diameter and approximately 6 inches in height was driven into the ground for a depth of several inches. Two area inches of water were poured into the cylinder and the time required for the water to disappear from the soil surface was noted. The values thus derived were converted to inches per hour infiltration. Infiltration rates were as follows:

Land-use	Infiltration rate per hour (Inches)
Channel area	.0
Lower pasture	0.56
Upper pasture	3.00
Cornfield	4.00
Coppice forest	6.00

Before grazing started on the abandoned cornfield in 1950, a similar infiltration study was made over the entire area and was repeated after each period of rotational grazing. Data in the following table show that it does

not require many animal use days to decrease the ability of the soil to take in water. Changes in infiltration rate were as follows:

	Infiltration rate per hour (Inches)
Before grazing	3.02
After 15 animal-use days per acre	1.55
After 30 animal-use days per acre	0.62

A similar surface infiltration study was begun in 1951. The entire watershed was gridded and monthly infiltration tests were made during the summer months on more than one hundred plots. These observations are to be continued for several seasons and the data are to be used as the basis for a special investigation on infiltration.

Mechanical analysis.--The objective of a mechanical analysis is to determine the size distribution of the individual particles within the soil. These results may be expressed by soil texture. Soil texture, other things being equal, influences the amount of surface area of the soil particles, which in turn affects the water-holding capacity of a soil. Retention storage, or water held in the capillary pores of mineral soils against the pull of gravity, is greater in silts and clays since the surface area exposed to water is many times greater than in sands. On the other hand, a high content of sand frequently provides greater opportunity for the development of large non-capillary pores and thus increases detention storage.

In preparing the samples for the mechanical analysis, the larger clods and aggregates were broken down and the entire sample placed on a 2 mm. sieve. The weight of the material which remained on the sieve after shaking, was noted. This material consisted largely of pebbles, rock fragments, and concretions. From these weights and from the total weight of the sample, percentages were calculated. To determine the mechanical composition of the portion of the samples passing through the 2 mm. sieve, the Bouyoucas (8) hydrometer method of mechanical analysis was employed.

From the results of these analyses it appears that the treatment applied to the watershed has not effected any large scale changes in the mechanical composition of the less than 2 mm. fraction of the soil. There is little variation indicated in either soil layer among the average values for each site. The undisturbed forest and the coppice forest show the highest content of sand, and the coppice forest has the lowest values for fine clay. The pastured areas are lowest in sand content and highest in fine clay. In view of these results, the two forested areas should show higher detention storage and lower retention storage than the pastured areas. The samples for the cornfield indicated intermediate detention and retention values between the pasture and the forest.

If, however, the materials greater than two millimeters in diameter have an influence similar to sand, then the undisturbed forest might be in a less favorable situation since it contains much less of this coarser fraction than any of the other plots.

Aggregate analysis.--One of the primary objectives of an aggregate analysis is the determination of the extent to which the finer mechanical separates are aggregated into coarser fractions. An aggregate analysis thus provides a measure of soil structure. Soil-water relations and aeration conditions are both strongly influenced by soil structure. The total percentage of aggregates or "state of aggregation" as suggested by Baver (6), gives a good indication of the erodibility of soils. If, for example, the state of aggregation is high, i.e., the soil contains a high content of water-stable aggregates, susceptibility to erosion is considerably lower than in the case of low aggregate stability. In the latter case there is little binding together of the particles into granules, and, consequently, falling raindrops and surface flow tend to disperse the soil. Under such conditions the soil takes up water more slowly and is obviously highly erosive.

In making aggregate analyses of the samples used in this study, Yoder's (30) dunker or wet-sieving method was employed. The five oven-dry core samples from each site and each layer were mixed and two composite samples extracted. Aggregate analyses were then made on the composite samples.

The results of this analysis indicate that the treatment of the watershed has effected a marked change in the stability of soil aggregates and consequently, soil structure. In both the surface and subsurface layers, but particularly in the surface, the undisturbed forest shows a considerably higher content of water-stable aggregates greater than 2 mm. in diameter than all other sites except the coppice forest. Even here, in the surface layer a difference of over 10 percent exists. These differences are particularly significant when one considers that the undisturbed forest contained much smaller quantities of coarse material (sand and particles 2 mm. in diameter or larger) than the other sites studied.

An analysis of the degree of aggregation in the fine earth material indicated similar results, with the forested areas showing even higher aggregation here than in the case of total water-stable aggregates.

From field observations the greatest part of the soil loss from the watershed is obviously from the cornfield and the lower pasture. The changes in aggregation or structure of the surface soil have no doubt contributed materially to these differences in soil losses. The marked changes in soil structure as indicated by aggregation further contribute to the changes in permeability and consequently to runoff characteristics which are noted later.

Soil organic matter.--The presence of a high content of organic matter in a soil has a marked influence on the storage capacity that a soil has for water. Detention storage, i.e., water detained temporarily in the large noncapillary pores, is increased by the inclusion of organic matter because of its influence on soil structure. Decaying roots and greater biological activity also result in the formation of the large hydraulic pathways which channel water through the soil profile and eventually to ground water.

Similarly, retention storage--that water retained or held in the soil and made available for plant growth--is usually increased through the incorporation of additional organic matter. Organic matter has a high moisture-absorptive capacity. In the colloidal state it takes up as much as 4.4 times its own weight of water. When decomposed and mixed with the soil, it coats

the soil particles with a gel-like porous and highly adsorptive substance. Clinging to the particles, this material, in effect, increases their surface areas and thus their storage capacity.

In this study, a determination was made of the organic matter contained in the samples collected from the watershed. In making these determinations, the dry combustion method patterned after the work of Schollenberger (21) was employed, i.e., measuring the amount of carbon dioxide evolved in the combustion of the soil and converting the carbon dioxide content into percent organic matter using a conversion factor of .471. The results of this analysis are given in table 2.

Table 2.--Summary of physical characteristics of the soil

Site	Volume weight	Total porosity	Capillary porosity	Non-capillary porosity	Permeability	Organic matter content	Sand and coarser material	Aggregates over 4mm.
		Percent	Percent	Percent	In./Hr.	Percent	Percent	Percent
0-3 inch layer								
Undisturbed forest	0.88	56.8	36.1	20.7	171.1	7.03	81.7	85.5
Coppice forest	.82	60.5	36.0	24.5	163.0	8.97	91.4	73.2
Upper pasture	1.03	53.9	39.0	14.9	20.2	7.62	99.6	64.1
Lower pasture	1.11	52.5	37.9	14.6	6.6	4.00	97.7	53.9
Cornfield	.93	56.1	40.1	16.0	12.4	4.40	99.1	59.0
Control plots (cornfield)	.98	53.8	29.2	24.6	85.0	7.28	91.0	46.2
3-6 inch layer								
Undisturbed forest	1.05	54.9	32.6	22.3	64.2	4.87	82.8	73.8
Coppice forest	.98	57.1	37.0	20.1	94.7	5.51	97.4	63.5
Upper pasture	1.07	56.2	37.7	18.5	16.9	4.41	95.8	48.6
Lower pasture	1.28	50.5	35.4	15.1	2.7	2.43	90.4	56.7
Cornfield	1.06	56.1	40.5	15.6	8.9	4.58	95.6	62.2
Control plots (cornfield)	1.06	51.0	37.9	13.1	64.0	4.62	89.9	40.1

In the surface layers, all areas except the lower pasture and the cornfield show values greater than 7 percent organic matter. This is probably the result of contributions to the litter by the slash accumulation and the heavy herbaceous cover following clear cutting. Similarly, the upper pasture and the control plots in the abandoned cornfield show a higher content of organic matter than the undisturbed forest. In the case of the upper pasture, this is possibly due to minimum usage by cattle, heavy herbaceous and shrubby ground cover, and to the fact that the vegetation is cut back or sprouted periodically, thus increasing the amount of litter accumulated on the soil surface. The high average value for the control plots in the cornfield is apparently the result of two seasons abandonment, permitting the development of a good ground cover and consequent litter accumulation. For the surface layer, this value is considerably higher in comparison with the cornfield, which has been grazed since abandonment. In the subsurface layer it is noted that the values for the two areas are approximately equal.

In comparison, the lower pasture and the cornfield show values considerably lower than the undisturbed forest and less than half the content of the coppice forest. The results of row cropping and overgrazing are thus apparent in the differences in soil organic matter.

In the subsurface layer, 3-6 inches, all values are lower by 1-1/2 to over 3 percent than in the surface layer, except in the cornfield, where the similarity of organic content in the two layers is the result of their mixing by the recent plowing and cultivation. The subsurface layer of all plots, except the lower pasture have similar organic contents. The organic content of the subsurface layer of the lower pasture is only about one-half as great as in the other plots. This difference together with the lower content of organic matter in the surface layer of this area as compared to the upper pasture indicates differences in the soils of these areas that are not entirely due to current management differences.

Porosity.--Soil porosity is undoubtedly one of the most significant of all physical soil properties in hydrologic studies. From a hydrologic standpoint, the primary function of a soil is that of a storage reservoir. This storage reservoir acts in the same fashion as a large dam project. In the case of floods on dam-protected streams, the flood waters accumulate first in the reservoir. After satisfying the initial storage in the reservoir, the water continues to accumulate in the overflow reservoir storage and is detained temporarily until it can be safely released to the stream below. Following the storm period the temporary storage is released as rapidly as possible until normal storage capacity is reached. The water left in the reservoir is retained and released slowly for use as irrigation water, for power generation, municipal supply and other uses.

A good soil reservoir should act in the same manner. The storage capacity of a soil or its pore volume is divided into two classes, capillary and noncapillary. The noncapillary pores consist of those spaces between the soil particles or soil aggregates that are so large that absorption and film forces cannot retain all the water in them against the pull of gravity. Thus, water is held in them only temporarily, similar to the overflow reservoir. Such storage is termed detention storage by the hydrologist.

The small capillary pores in the soil provide the hydrologist's retention storage. Water in the capillary or retention storage reservoir is held against the force of gravity but is subject to the pull of evaporation near the surface of the soil and to transpiration at any depth where living roots occur. Part of the water thus retained in the soil is utilized by plant growth or is dissipated from an area by evaporation. This retention storage reservoir in the soil acts as the normal reservoir of a river system.

To determine the porosity values for the samples used herein, the 3 x 3 inch soil cores were saturated, weighed and placed on a tension table for approximately 24 hours at a tension of 40 centimeters. The weights were recorded and these values were used in determining noncapillary or detention storage. After weighing, the samples were oven-dried at 105°C. and reweighed to determine capillary or retention storage as well as volume weight. The average values obtained for noncapillary, capillary and total pore space are presented in table 2.

Volume weight.--Volume weight may be defined as the ratio between the dry weight of a given mass of undisturbed soil and its volume. The usual method of determining volume weight, or, as it is frequently termed, the apparent specific gravity or bulk density, is to divide the oven-dry weight of the undisturbed soil in grams by the volume of space which this soil occupies in cubic centimeters.

The volume weight of a soil is dependent for the most part on structure and organic matter content. Ordinarily, very compact soils with low pore volume and low aggregation possess high volume weights. On the other hand, porous, well aggregated soils show low volume weights. Similarly, soils with a high content of organic matter have a lower specific gravity as well as a lower volume weight than those with a low content of organic matter. Forest soils, because they usually have a higher content of organic matter, show lower volume weights in their surface layers than grazed or cultivated soils.

In determining the volume weights, the oven-dry weight of the soil core in grams was divided by the volume of the core in cubic centimeters. Where soil cores were not full, volume corrections were made by filling the depressions with sand and then measuring the volume of sand utilized. Table 2 shows the average values for the six sites for both the surface and subsurface layers.

The average results given in table 2 indicate that in the surface layer both the undisturbed forest and the coppice forest areas have more favorable soil-water relations than the other areas. The highest values in both the surface and subsurface layers were found in the lower pasture. In the subsurface layer, although the two forest areas show slightly lower values, the variations are small except for the lower pasture. As might be expected, all values for the subsurface layer are somewhat higher than in the surface layer of the same area. The results tend to indicate a poorer physical condition of the surface layers in the lower pasture, which would substantiate field observations on surface runoff conditions.

Permeability.--The permeability of a soil is ordinarily considered to be the rate at which water moves through the soil column. It differs from

infiltration in that the latter is concerned only with the rate at which water enters the soil. It is evident then that infiltration and permeability together provide important measures of physical soil characteristics from the standpoint of surface runoff phenomena. A soil may have a high infiltration rate and a low permeability rate or the permeability rate may be high and a "surface bottleneck" may be present, giving a low infiltration rate. In either case, or if both values are low, comparatively little water can be stored and transmitted through the soil, and high surface runoff results.

Since soil moisture deficits must be satisfied before water starts permeating or percolating through the soil column, permeability determinations were made on saturated soil cores. As nearly as possible a 1/2-inch head of water was maintained on the soil core for a period of 1 hour. The permeability rate was determined by measuring the amount of water which percolated through the soil core in that time. In extremely permeable cores 1/2 hour was used and the resulting values doubled. The results of these determinations are shown in table 2.

Permeability tests show much greater differences in the different land use areas than the other physical soil analyses. Both forested areas show very high permeability rates in both the surface and subsurface layers. The upper pasture, cornfield and, particularly, the lower pasture show very low rates in comparison. The rates indicated for the control plots approach those of the forested areas, which apparently reflect the effects of 2 years of abandonment. By far the lowest rates in both layers are those for the lower pasture, undoubtedly the result of overgrazing with its consequent compaction.

According to Baver (6), Lassen, Lull and Frank (18), and Fletcher (11), permeability or percolation is dependent upon the noncapillary pore volume. As indicated previously, noncapillary porosity decreased as a result of the treatment to the watershed although the decrease was only in the magnitude of approximately 6 percent. Assuming that noncapillary pore space determined permeability, from these data it appears that relatively small changes in this pore volume may effect very marked changes in the permeability rate.

The values noted for the infiltration rate indicate a trend similar to that for the permeability rate. The changes indicated for both the infiltration rate and the permeability rate indicate a close relationship with the changes in surface runoff noted in the sections which follow. However, the fact that infiltration rates were much lower than permeability rates shows that the immediate surface of the soil is the limiting factor in moisture detention and is causing increased surface runoff on the Little Hurricane Watershed.

HYDROLOGIC DATA

The basic data in nearly all hydrologic investigations are measures of precipitation, or recharge, and stream flow, or discharge. The volume and rate of discharge from a given watershed or hydrologic unit is a reflection of the amount and intensity of precipitation which it receives and the characteristics of the watershed. The manner in which these factors are

measured on the Little Hurricane Watershed and the methods employed in converting the raw data into usable form have been noted previously.

Precipitation

The total weighted precipitation received by the watershed, as measured by three standard rain gages servicing the area, is summarized by hydrologic years in the following tabulation. The hydrologic year runs from November to October. Data for 1934 and 1951 are incomplete.

Hydrologic year	Precipitation (Inches)
1935	61.94
1936	84.84
1937	72.85
1938	63.72
1939	74.76
1940	56.79
1941	50.33
1942	67.81
1943	77.70
1944	66.64
1945	65.21
1946	79.13
1947	69.00
1948	71.08
1949	107.18
1950	76.22
Average	71.54

Figure 12 indicates the average monthly precipitation as well as the area inches of stream discharge by months and by hydrologic seasons. Precipitation, vegetation, and soil conditions are all reflected in the discharge curve. From January through March precipitation is at its maximum. Evaporation and transpiration are at a minimum and soil moisture conditions are at their peak. Much of the precipitation which occurs during these months filters rather rapidly through the soil reservoir into ground water, since soil moisture deficits are very low. Consequently, stream discharge is at its highest level. A large portion of the water appears as clean, non-turbid water from subsurface and ground-water flow. The majority of the storms during this season produce low-intensity precipitation and some snow, which ordinarily does not accumulate to great depths to form flood hazard conditions.

Throughout April and continuing into May, precipitation steadily declines. At the same time vegetation commences growing, temperatures increase and consequent losses to evaporation and transpiration also increase. Starting in May and continuing throughout June and part of July, precipitation increases rather sharply. Likewise, evaporation and transpiration are increasing and the discharge curve indicates only a slight rise as a result of the increased precipitation. Starting in July and continuing through October, precipitation steadily declines as evaporation and transpiration continue to make heavy demands. This is indicated in the discharge curve, in that stream

Figure 12.--Average monthly precipitation and stream flow.

discharge is at its lowest ebb during September.

October marks the end of the growing season and with it comes a sudden decrease in both evaporation and transpiration. At the same time the precipitation curve swings sharply upward. Stream discharge shows a gradual climb until the soil moisture deficits resulting from the heavy use by vegetation and evaporation are satisfied. The cycle is completed in the winter months when soil moisture deficits are met and ground water recharge again occurs.

In studies of individual storms and their effects on stream discharge, a measure of precipitation intensities as well as a measure of total amounts are required. Recording rain gages 67 and 1 were used to obtain precipitation intensities. The precipitation intensity values as well as the mass or accumulated precipitation values are taken from the precipitation intensity records and are shown graphically along with stream discharge for representative storms used in this study in figures 13 and 14.

An examination of individual storms shows that prior to treatment bursts of precipitation usually resulted only in a continued steady increase in stream flow. Following the clear cutting of the forest and the initiation of mountain farming, relatively small bursts of precipitation resulted in immediate and sharp increases in stream flow. The treatment of the watershed has thus resulted in producing stream flow of extremely "flashy" characteristics.

Stream Flow

Gage height readings recorded for the weirs used in measuring discharge from the watershed are converted to cubic feet per second from rating tables calculated for the respective stream controls. Since precipitation is expressed in inches and in inches per hour, the cubic feet per second values were converted to inches per hour to aid in graphic presentation and analysis. The discharge values in inches per hour were plotted over time to give the storm hydrographs for individual storms. Hydrographs for representative storms used herein are given in figures 13 and 14.

Definition of Storms

Frequently, precipitation is received in such small amounts and at such low intensities that it produces no perceptible change in the stream hydrograph. All or the greater part of it may be intercepted by vegetation. Sufficient precipitation must occur to satisfy initial depression storage (water required to fill the small depressions on the soil surface) as well as vegetation interception before it can run off or otherwise enter the stream. Many small rises in stream hydrographs following a brief low-intensity period of precipitation are caused by precipitation falling in the channel or stream itself rather than by surface runoff or some form of subsurface flow. Unless an investigation is concerned with total water yields, the inclusion of all periods of precipitation is impractical. Consequently, for individual storm studies, there must be some dividing line or definition of what constitutes a storm.

After examining all the precipitation and stream-flow data, the arbitrary standard of a maximum 30-minute intensity of at least 0.90 inch per hour was selected. An exception was made in one case in which the maximum 30-min-

ute precipitation intensity was less than 0.90 inch per hour where the peak stream discharge greatly exceeded "normal" for the amount and intensity of the precipitation received.

Classification of Storms

Streams, particularly from small watersheds, respond quite differently to different storms. Consequently, based upon the patterns of precipitation and the stream hydrographs resulting therefrom, all storms were classified naturally into three categories: summer, winter, and intermediate. Summer storms are characterized by short but intense periods of rainfall. They are usually occasioned by frontal activity or convection storms. Summer storms are further subdivided into unit or single storms and multiple storms. The unit summer storm yields nearly all of its precipitation in bursts which are bunched closely together, and produces a single peak on the hydrograph. The multiple summer storm produces intense precipitation bursts which are separated by a period of time not exceeding 6 hours, in which precipitation may stop entirely or be of low intensities. A hydrograph of two or more peaks results. Graphs A and B in figure 13 show the precipitation patterns and the resultant hydrographs of the unit and multiple summer storms respectively.

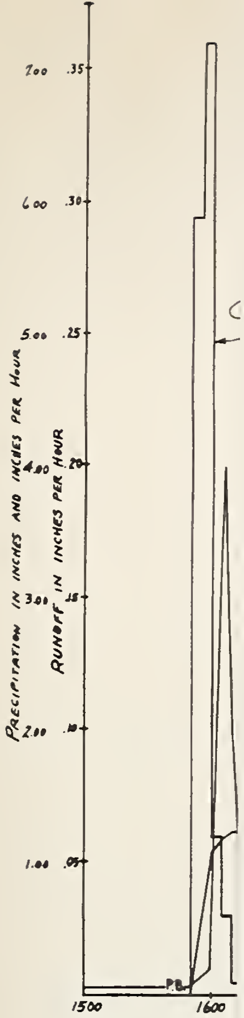
The intermediate storm is characterized by precipitation which comes alternately in short intense bursts followed by periods of precipitation of more moderate intensities. It usually yields a greater amount of precipitation than most summer storms and is usually associated with the spring and fall seasons. The tropical hurricanes which reach this area fall into this classification. The hydrographs produced by such storms are marked by a series of peaks and troughs. Graph C in figure 13 illustrates a typical intermediate type storm.

The winter storm gives a relatively large volume of precipitation which usually does not come at the higher intensities associated with summer storms. However, the winter storm is usually of much longer duration as it is most frequently the result of cold front activity. Graph D in figure 13 illustrates the precipitation pattern and the hydrograph of a characteristic winter storm.

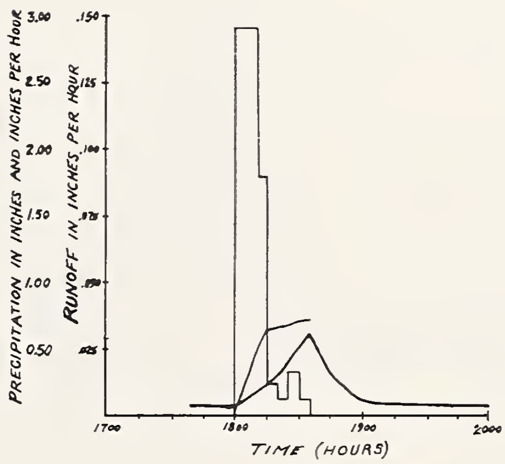
Distribution of Storms

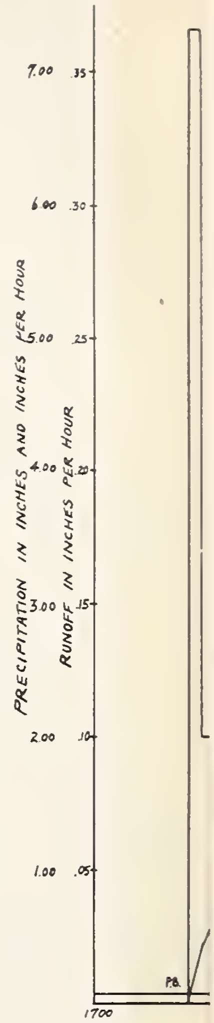
An analysis of a listing of storms producing peak flows exceeding 9 cubic feet per second per square mile made by Johnson[5/] and continued through August, 1951 by the writer, indicates that from the standpoint of the distribution of flood-producing storms, the summer storm is the most significant (fig. 15). Similarly, 12 of the recorded 14 flood peaks which exceeded 100 c.s.m. resulted from summer storms.

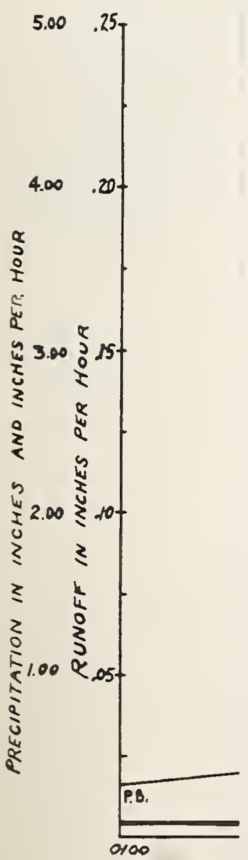
5/ Johnson, E. A. Summary of Flood Peaks over 9 c.s.m., Watershed No. 3, 1949 (unpublished compilation, Coweeta Hydrologic Laboratory).



A Summer-type storm, June 15, 1937







D Intermediate-type storm, September 30, 1936

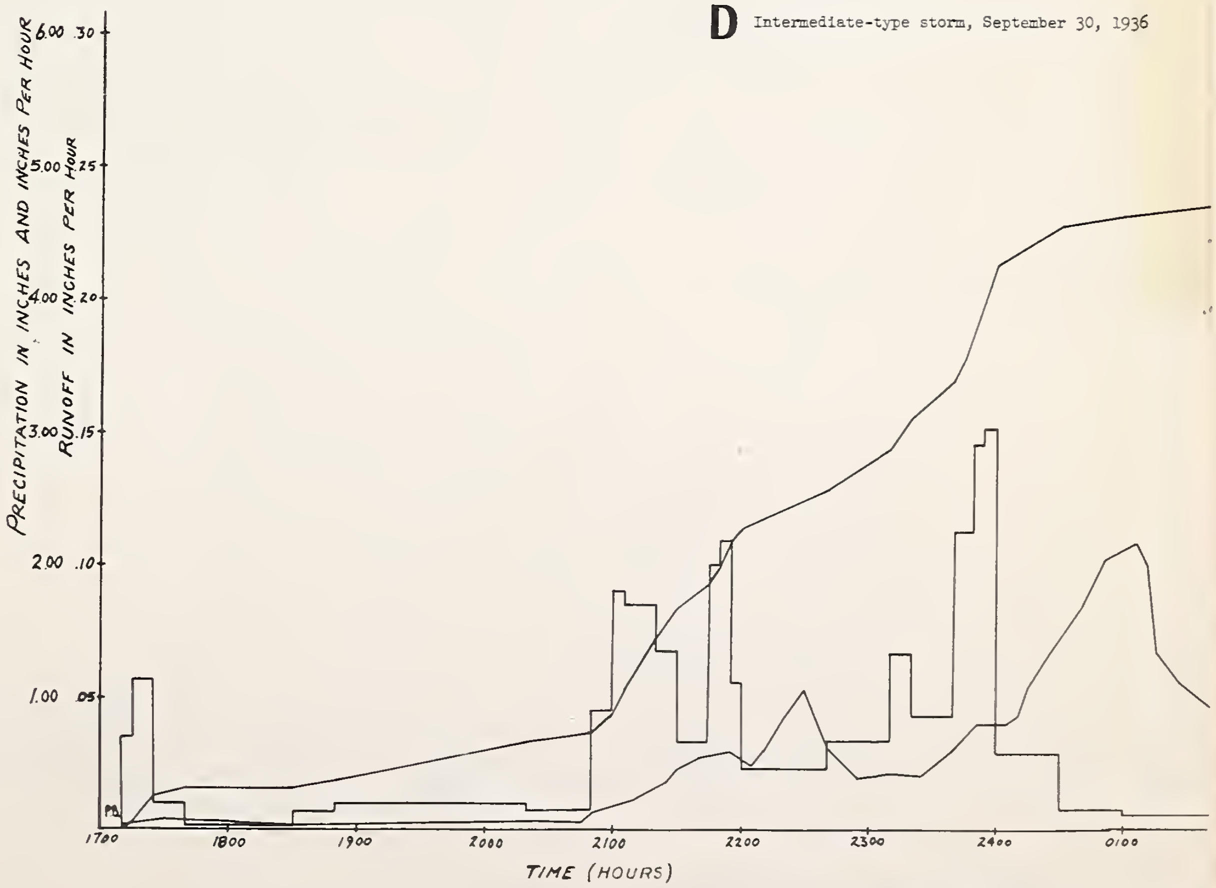


Figure 14.--Precipitation rate, mass precipitation and

Fold-out Placeholder

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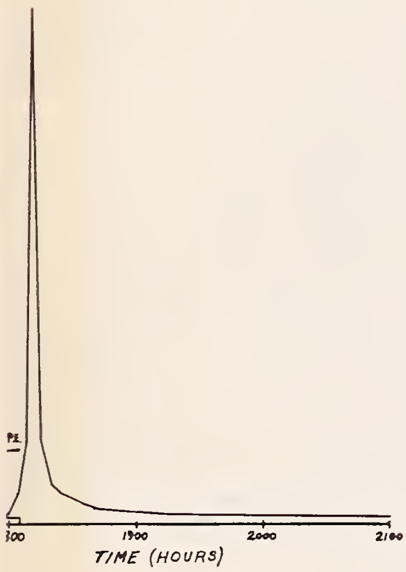
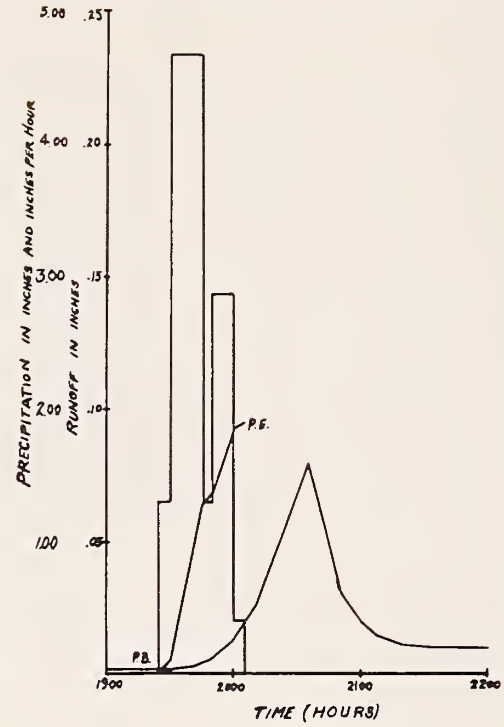
TIME (HOURS)

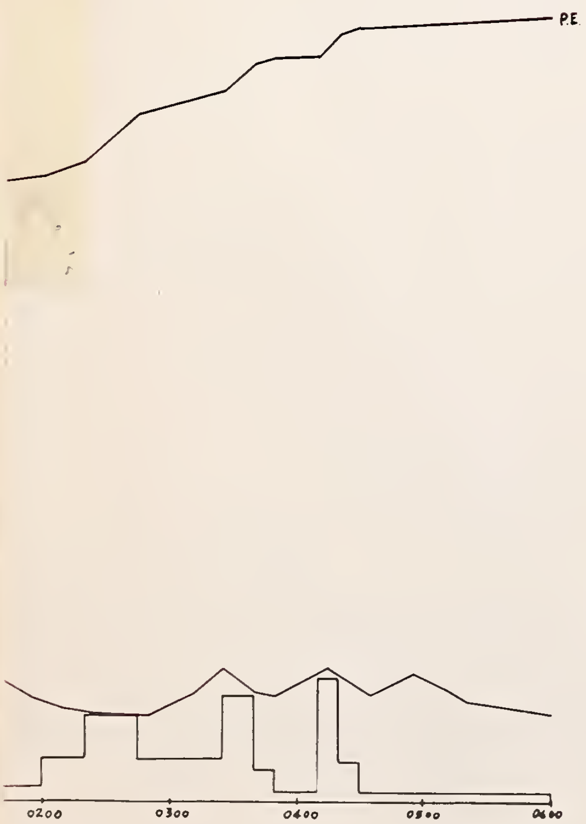
Figure 14.--Precipitation rate, mass precipitation and

B Summer-type storm, August 4, 1943

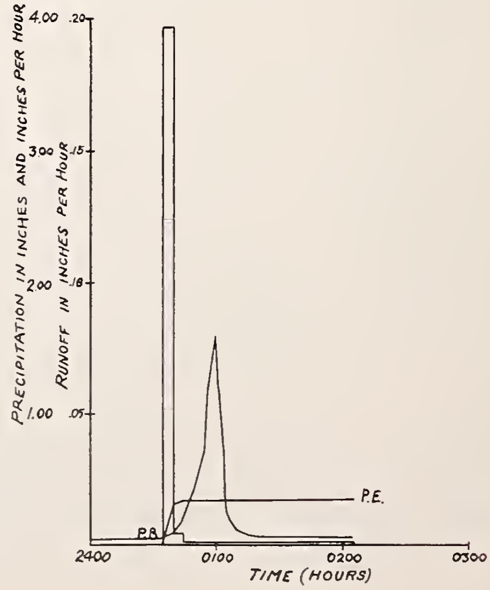


C Unit summer storm, August 22, 1935





E Summer-type storm, August 20, 1949



stream hydrograph for different types of storms on the study watershed.

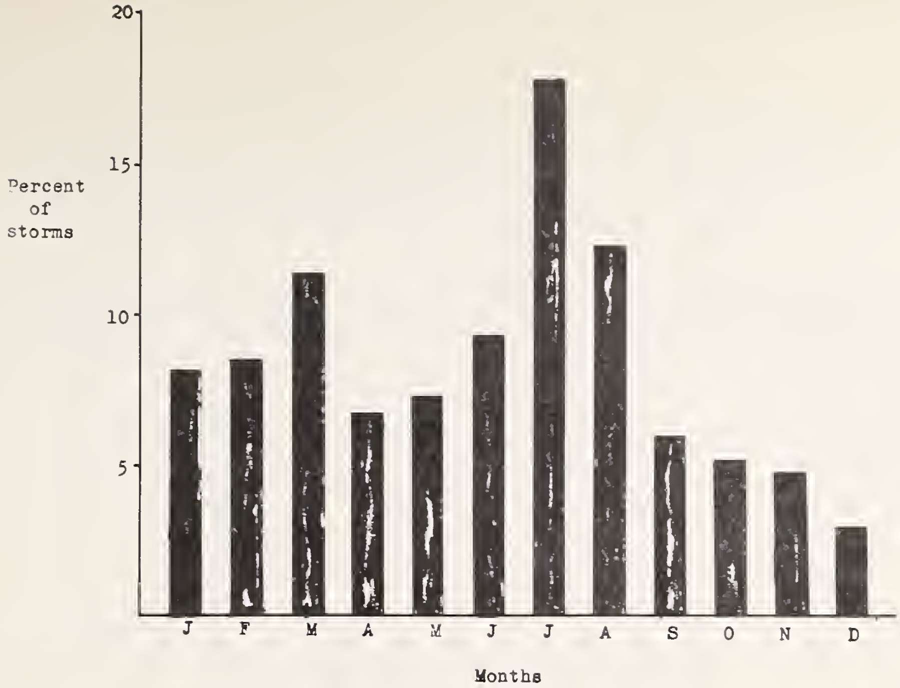


Figure 15.--Distribution chart, Little Hurricane Watershed, shows that over 39 percent of flood-producing storms occur in June, July, and August.

CHANGES IN RUNOFF CHARACTERISTICS

Probably the most important single tool of the hydrologist or watershed manager is a knowledge of the stream flow and runoff characteristics for a given drainage area. A knowledge of these characteristics guides the engineer or land manager in planning flood control measures or permits municipalities to select and manage watershed lands as well as to regulate consumption. Considerable attention has been given to the study of streamflow characteristics on large basins, particularly within the past 10 years, by the United States Department of Agriculture and the United States Corps of Engineers. Numerous investigations have been made to determine primarily gross runoff characteristics from small watersheds and plots.

It is the intent of this study to determine not only the percent of total runoff, but to evaluate any changes in surface or storm runoff in terms of flood peaks, the frequency of floods and the manner in which storm water actually runs off a small watershed. No attempt has been made, however, to study any changes in base or subsurface flow or total water yields.

Runoff Percent

One frequently used method of expressing surface runoff is runoff percent or the calculation of the percentage of total precipitation which comes off the drainage area in the form of overland flow. To evaluate the gross changes in surface runoff, an analysis of the runoff percent for the watershed in forest cover and following treatment was made.

The total storm runoff for all storms from the watershed while in forest cover (1934-1939) averaged 2.66 percent of the precipitation. Following forest cutting and mountain farming, this value increased to 4.50 percent. For summer storms only, the difference is more marked. Under forest conditions, a runoff percent of 1.53 was noted, compared with 4.79 percent following the treatment. This represents an increase of 3.26.

percent, which at first may appear rather insignificant; however, in terms of volume for a 2-inch storm as defined herein, this amounts to over 5,500 cubic feet. The following tabulation shows the increased storm runoff resulting from summer storms of 1/2 to 5 inches precipitation.

Storm precipitation (Inches)	Increased volume of surface runoff (Cubic feet)
0.5	1398
1	2756
2	5512
3	8268
4	11024
5	13780

Changes in Flood Peaks

Flood peak magnitudes and frequencies are both valuable tools used to express and evaluate the effects of various land use practices. These factors are both used frequently to aid in the determination of the economic design of engineering structures and in flood control programs.

Flood peak magnitudes.--One of the most pronounced changes in surface runoff occurring as a result of forest cutting and subsequent mountain farming is the increase in the magnitude of flood peaks. To obtain a measure of this change, a flood peak magnitude study was made. Similar studies were made on this watershed in 1949 and 1950.[6/] After an examination of the previous analyses, however, it was believed that the results therefrom were not entirely satisfactory.

The first step in such a study is the collection and cataloging of storms on some rational bases. In the earlier studies a specified minimum peak was used as a basis for storm comparison. The writer believed that a more satisfactory bases for comparison was the storms themselves, i.e., a certain amount and intensity of precipitation. Consequently, for this study, storms with a maximum 30-minute rainfall intensity of over 0.90 inch per hour were arbitrarily selected.

An orientation analysis was made in which the peak discharges in cubic feet per second per square mile were plotted against the maximum 30-minute precipitation intensities by periods. Three periods were selected: 1934-1939, 1940-1945, and 1946-1951. The 1934-1939 period represents the pretreatment period in which the watershed was in forest cover; 1940-1945, the intermediate period, in which the mountain farming treatment was applied and in which the soil gradually lost its original structure, organic content, and fertility; and 1946-1951, the after period, in which the maximum effects of land use were in evidence.

From these graphs it was apparent, particularly in the pretreatment period, that intermediate and winter storms gave considerable spread to the points. A further examination of the storm data indicated that multiple

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6/ Unpublished reports, Coweeta Hydrologic Laboratory.

summer storms too were responsible for considerable dispersion of the points. An attempt was made to evaluate further the data on the basis of antecedent moisture conditions. Due to time limitations, additional analyses of antecedent moisture conditions have not been made.

Using only the selected storms, i.e., single or uniform summer storms, a new listing of storm peaks and corresponding precipitation intensities was made by periods and for maximum precipitation intensities of 15, 20, 30, and 60-minute intervals. For ease in handling, the data were grouped into 25 c.s.m. groups or classes (0-25, 26-50, etc.) and averages computed. The average c.s.m.'s for the group or class were then plotted against the class average precipitation intensities for each of the four precipitation intensity intervals for each of the three periods.

Least square linear regressions were calculated for all plottings and straight line curves fitted to the data.

The standard error of the estimate for the regressions was calculated for all four rainfall intensity intervals in the 1946-1951 period, and the 15-minute interval gave the lowest error. The time of concentration for the watershed following treatment was approximately 15 minutes; consequently, this interval was selected as best for purposes of comparison.

To show that the changes were not the result of changes in storm characteristics and precipitation patterns, the corresponding storm peaks from a control watershed were plotted against the rainfall intensities applied to watershed No. 3 for the 15-minute precipitation interval for the three periods. The resulting curves showing the relation between maximum discharge rate and precipitation intensity for both watersheds for the three periods are given in figure 16.

It is obvious from the curves for the treated watershed, that a marked increase in the magnitude of flood peaks has been effected. Similarly, the curves for the control watershed indicate that there has been no decided change in climatic conditions which might affect this increase. Consequently, the changes in flood peaks are attributed to forest cutting and subsequent land use.

The increase in flood peaks brought about by the treatment of the watershed for the maximum 15-minute period of precipitation at 2, 3, 4, and 5 inches per hour are summarized in Table 3 by actual flood peaks in c.s.m. as well as in percentage increases.

An additional study was made to show the changes in the magnitudes of flood peaks, using all storms with maximum 30-minute precipitation intensities exceeding 0.90 inch per hour. In this study the maximum flood peaks in cubic feet per second per square mile from watershed No. 3 were plotted against the maximum peaks recorded for the control watershed (No. 2) for the same storms for the 1934-1939 and 1940-1951 periods. Least square linear regressions were calculated and straight line curves fitted to the data. The results of this analysis are presented in figure 17.

The increased magnitude of flood peaks is even more marked than in the case when only unit summer storms were used. Prior to the treatment of watershed No. 3, a storm producing a flood peak of 30 c.s.m. on watershed No. 2 showed a peak of 41 c.s.m. on watershed No. 3. Similarly, a storm producing

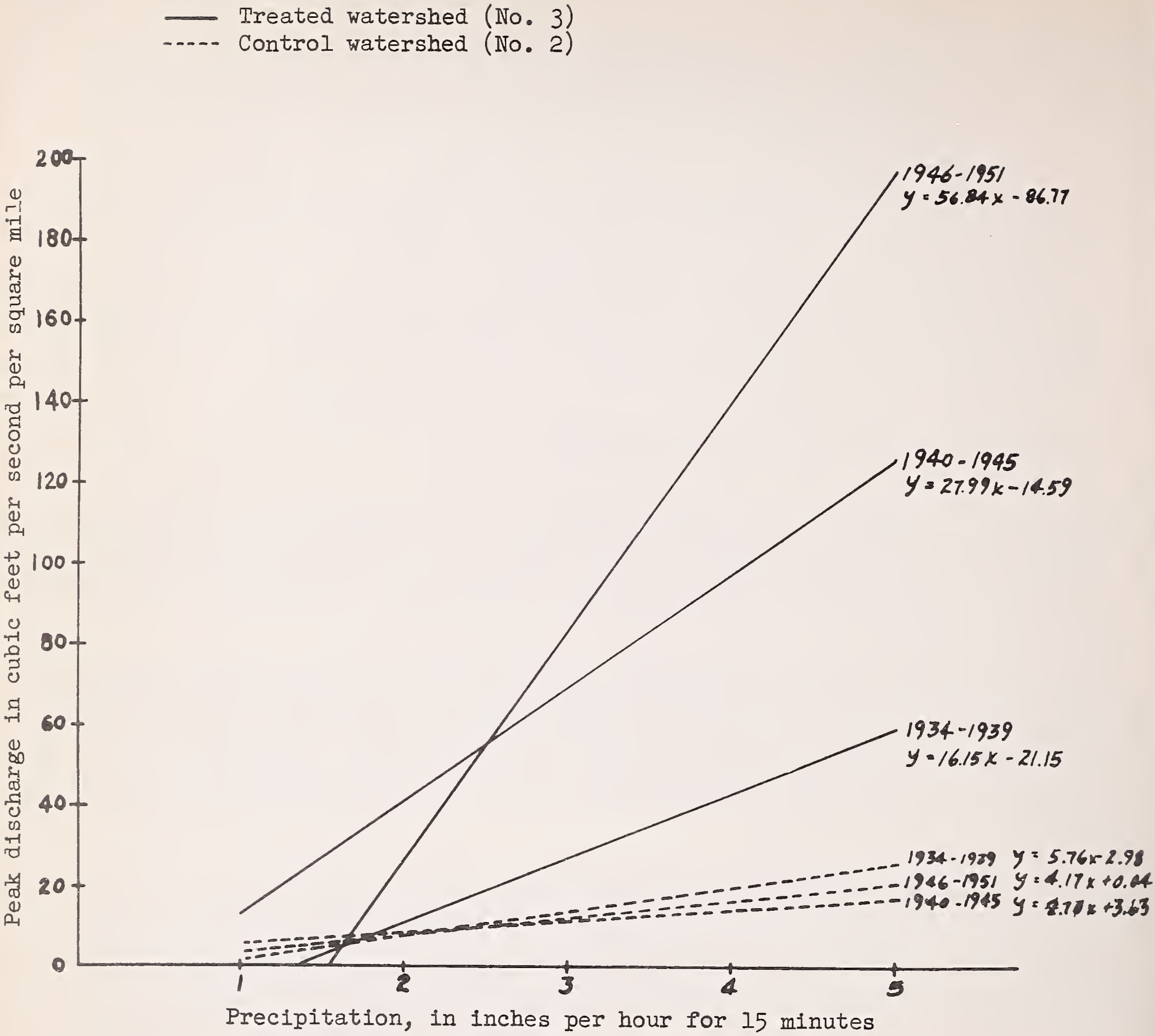

Figure 16.--The effect of forest cutting and subsequent mountain farming on maximum discharge rate, as related to precipitation intensity. Based on selected uniform summer storms having a maximum 30-minute precipitation intensity over 0.90 inches per hour.

a peak of 70 c.s.m. on watershed No. 2 produced a peak of about 85 c.s.m. for watershed No. 3. Following forest cutting and mountain farming, the peaks for watershed No. 3 corresponding to 41 and 85 c.s.m. values for the 1934-1939 period had increased to over 360 and 670 c.s.m. respectively.

In examining the individual storms and the resultant flood peaks, the highest flood peak recorded for the period that the watershed was in forest cover was 109 c.s.m. In the 11-year period following forest cutting and mountain farming 12 floods occurred which exceeded this former maximum peak. The highest peak recorded was that of July 10, 1949, which exceeded 1849 cubic feet per second per square mile. The two highest 5-minute precipitation intensities recorded during the 17 years of record, however, both occurred prior to 1940 while the watershed was forest covered.

Table 3.--Changes in flood peaks following forest cutting and mountain farming

Precipitation for 15 minutes	Peak for 1934-1939	Peak for 1940-1945	Increase over 1934-1939	Peak for 1946-1951	Increase over 1934-1939
Inches per hour	C.s.m.	C.s.m.	Percent	C.s.m.	Percent
2	11	42	382	27	245
3	27	70	260	84	311
4	43	97	226	141	328
5	59	126	213	197	334

From these analyses it is apparent that the treatment of the Little Hurricane watershed has effected striking increases in the magnitude of flood peaks.

Flood peak frequencies.--Even a cursory examination of the data reveals a marked change in the frequency of floods following forest cutting and treatment of the watershed. To get a quantitative measure of this change, a flood peak frequency study was made. The same standard used in the flood peak magnitude study, i.e., floods resulting from storms having a maximum 30-minute precipitation intensity of over 0.90 inch per hour, was used as the basis for this study, except that all storms, winter, intermediate and multiple as well as summer, were included.

The flood peaks for the watershed for the period in which the watershed was in forest cover, 1934-1939, and the treatment period, 1940-1951, were classified separately into 10 c.s.m. groups and arranged in order of magnitude. Mass totals were then calculated in order of descending magnitude. From these values occurrence percentages were computed. The mid-points of the c.s.m. classes were then plotted against their corresponding percentages on a logarithmic scale and smooth curves fitted to the data to give the frequency curves in figure 18. A logarithmic scale was selected for the ordinate in order to emphasize the maximum flood peaks, since these are the values which are of greatest importance in watershed management and flood control work as well as in engineering structures for water and erosion control.

To show that the changes are a result of the treatment rather than of climatic fluctuations during the treatment period, the same procedure was followed for the control watershed which was in forest cover for the entire period, except that 5 c.s.m. classes were used to better define a curve in graphic presentation. Figure 19 shows these resulting frequency curves.

It is apparent from figure 18 that a decided increase in flood frequencies has been effected. Assuming an average of 50 storms of flood magnitude in 10 years, 12 flood peaks over 50 c.s.m. could be expected with the watershed in forest cover. Compared with this, 25 flood peaks in excess of 50 c.s.m. should occur following forest cutting and subsequent mountain farming. On the

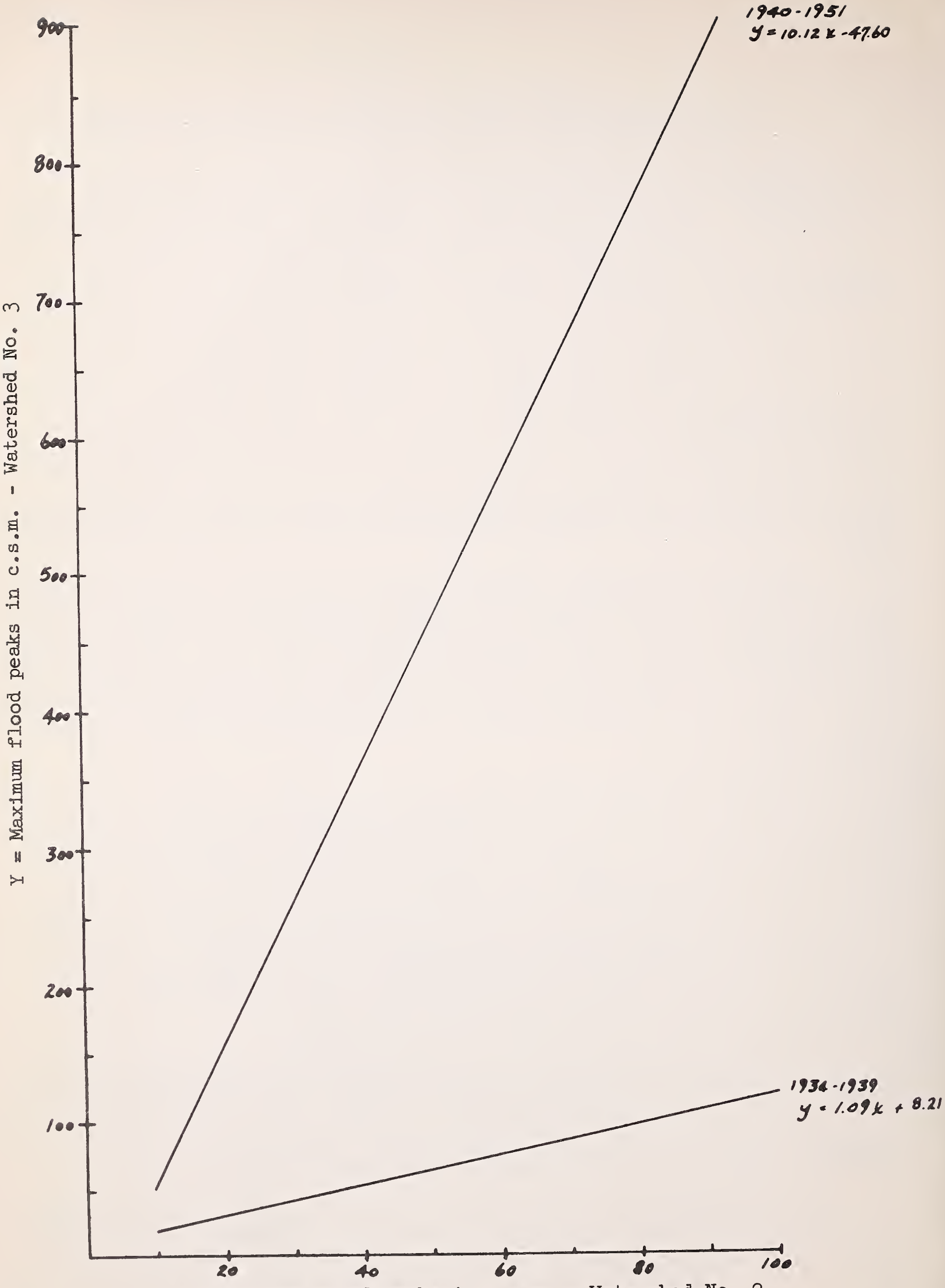

Figure 17.--Maximum flood-peak relation between control watershed No. 2 and study watershed No. 3. Based on all storms with a maximum 30-minute intensity over 0.90 inches per hour.

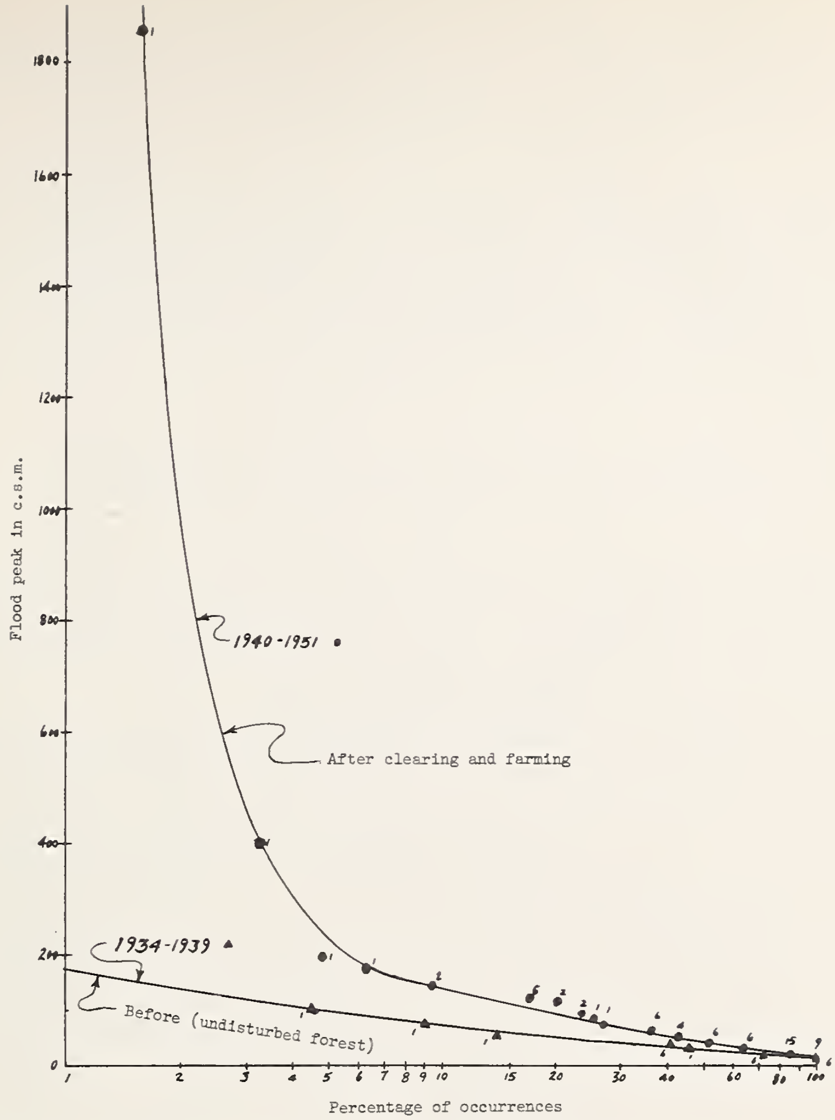

Figure 18.--Frequency of flood peaks, study watershed (No. 3).

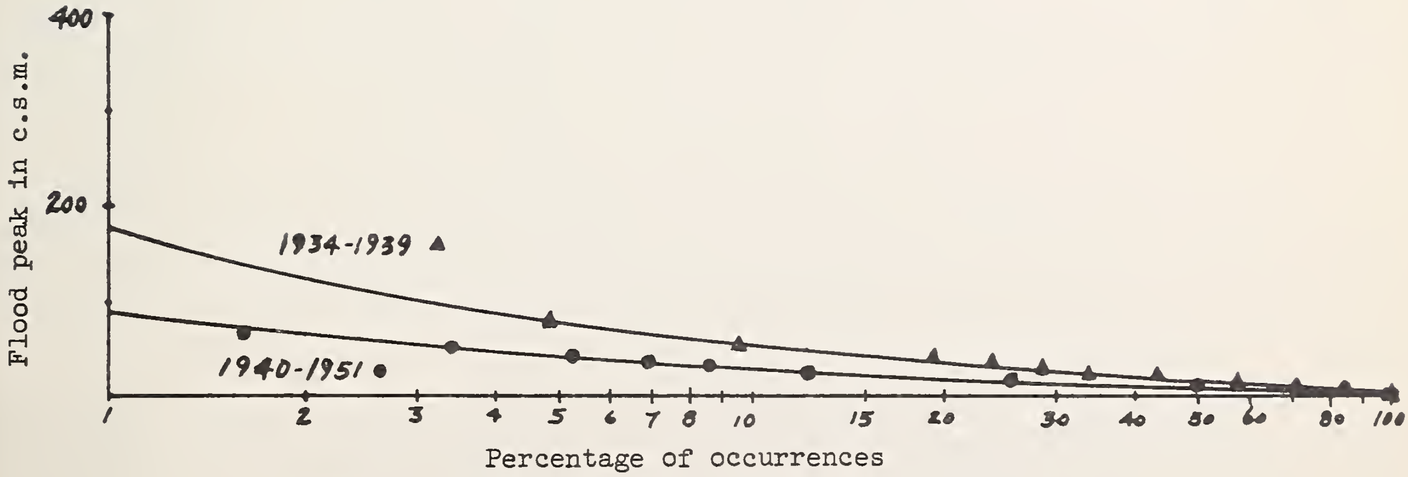

Figure 19.--Frequency of flood peaks, control watershed (No. 2).

same basis, at the 100 c.s.m. level, only 2 to 3 flood peaks from the forested watershed could be anticipated as compared with at least 10 flood peaks in excess of 100 c.s.m. from the treated watershed.

The corresponding curves for the control watershed (fig. 19) show that no great change has taken place in the precipitation pattern. Actually, the 1934-1939 period shows higher flood frequencies than the post-treatment period, indicating that possibly, had climatic conditions been even more alike for the two periods, the changes brought about on the treated watershed would have been even more marked.

Table 4 summarizes the changes in flood peaks at the 1, 2, 5, 10, 20, 50 and 80-percent levels for the Little Hurricane Watershed.

This increase in flood frequency, along with the increased magnitude, aids in explaining why channel bank vegetation is being removed and why the vegetation which starts growing on this site is washed away before it has an opportunity to become firmly established.

Table 4.--Frequency of flood peaks before and after forest cutting and subsequent mountain farming

Period	Percent of observations						
	1	2	5	10	20	50	80
	Maximum flood peak in c.s.m. exceeds....						
1934-1939	175	135	100	75	55	30	20
1940-1951	2000+	1000	230	130	100	60	30

Distribution of Storm Runoff

To show the effects of forest cutting and subsequent mountain farming on the manner in which storm runoff comes off the experimental watershed, distribution graphs were made for the two periods, 1934-1939 and 1940-1951. The method outlined by Wisler and Brater (29) was used to prepare the storm distribution graphs.

Five storms, two for the "before" period and three for the "after" period, were selected for this study on the basis of similarity in storm type and precipitation amount and intensity. The bases of the hydrographs were divided into 3-minute intervals and the total flow and the base flow were calculated for these intervals. Three-minute intervals were selected to give a total of approximately 20 equal intervals or points for subsequent graphical analysis. Storm runoff was obtained by subtracting base flow from total flow (unit hydrographs). Storm runoff percentages were then computed for each 3-minute interval. Storm data for before and after periods were averaged and these values plotted to give the final distribution graphs for the two periods which are shown in figure 20.

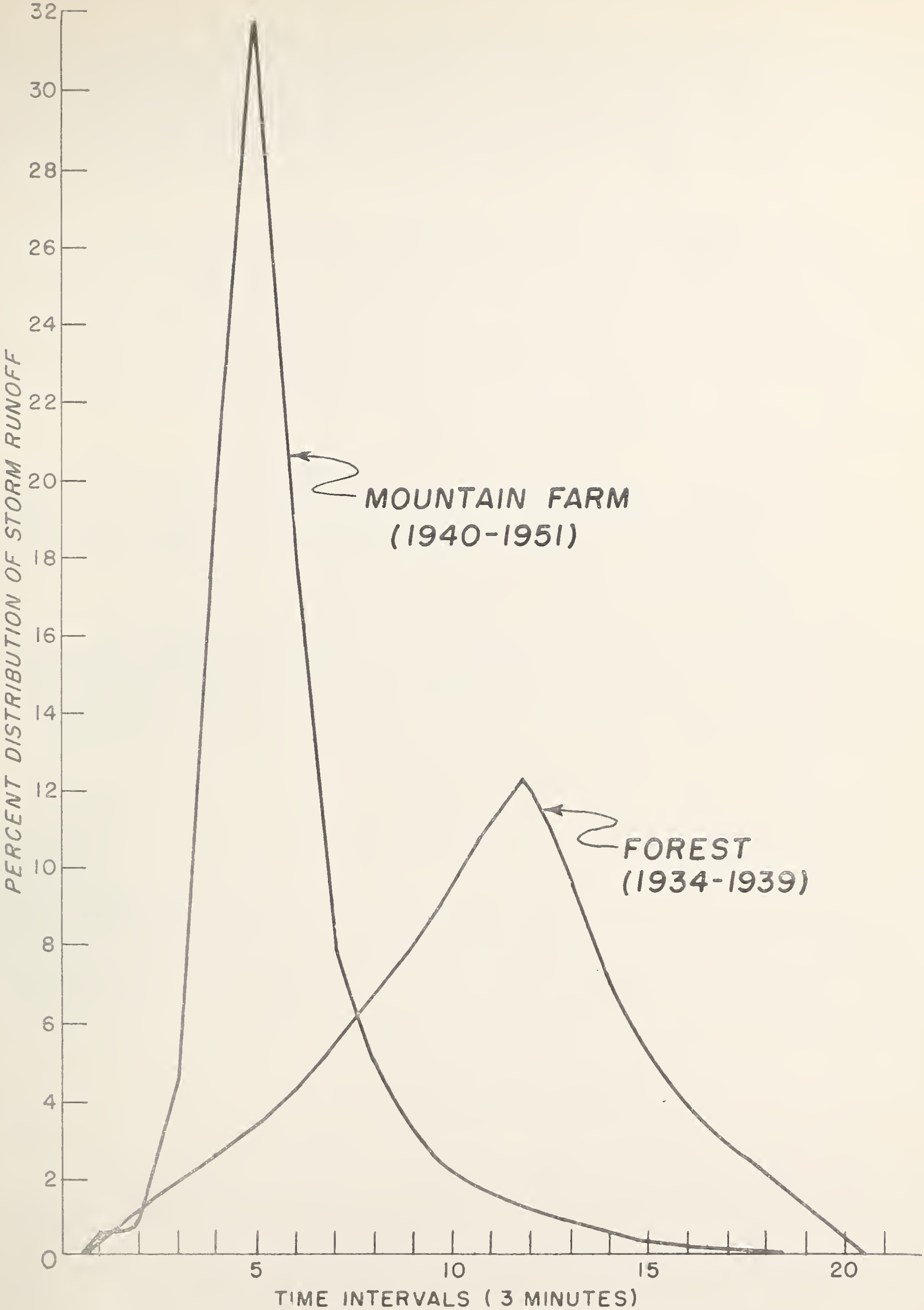

Figure 20.--Effects of forest cutting and subsequent mountain farming on the distribution of storm runoff.

To show the difference in the volume of storm runoff coming off the watershed at maximum flood stage, a time period equal to one-tenth the base of the hydrograph (3-minute interval on each side of the actual peak) was marked off on the distribution graphs and the percentages for these intervals were determined by planimeter. These results too are given in figure 20.

It is obvious from these graphs that a definite change has taken place in the distribution of the storm runoff. One notable effect is the change in the time of concentration (time that runoff began to the time of the maximum peak) for the watershed. While the watershed was in forest cover, the peak occurred approximately 35 minutes from the time storm runoff first began. Following forest cutting and mountain farming, the peak occurred on the average of 15 minutes after runoff began. In a few cases, with short intense summer storms, the time from the start of runoff to the peak was observed to be as little as 10 minutes.

It is apparent, too, that the peak percentage itself was more than doubled as a result of the treatment. While in forest cover, the maximum value was approximately 12 percent; following cutting and treatment, this value jumped to approximately 32 percent. Apparent too, is the change to an almost needle-shaped storm hydrograph.

Significant also is the change in the peak percentage based on the maximum discharge for a time period equal to one-tenth the base of the storm hydrograph. For the "before" period, this amounted to 24 percent of the total storm runoff. As a result of treatment, the peak percentage increased to 49 percent.

SUMMARY

For many years it has been a common practice in the Southern Appalachians to clear off the native forest cover on steep slopes and then to attempt to farm the cut-over area. In this study a determination of the effects of this use of land on some of the biologic, edaphic and surface runoff characteristics of a 23-acre watershed was made with the following results.

Biologic Changes

By clear cutting the forest cover and applying different land use practices to the watershed a marked change in the vegetation was produced. Nearly half of the watershed, approximately 10 acres, was permitted to grow back into natural forest cover. Eleven years after cutting and negligible use by cattle, the dominant sprouts and seedling trees are approximately 3 to 3-1/2 inches in diameter at breast height and 12 to 15 feet in height. By examining adjacent uncut areas and timber cruise data, it was found that there is little change in species composition in this coppice forest area except for the presence of wild plum, hawthorne and staghorn sumac. These invading species will probably disappear within a few years following complete canopy closure.

Shrubby and herbaceous cover in the coppice forest area is very sparse except along the ridges and in a few openings. Many species

associated with forest openings were observed, although most of these will probably disappear within a few years. In most of the adjoining forest area there is a moderate understory of mountain laurel and rhododendron. It is apparently much slower in becoming re-established than many other species since it is fairly common only near the ridges in the coppice forest area.

In the two pasture areas as well as in the abandoned cornfield, the most marked changes are those in vegetation density and in species composition of the shrubby and herbaceous cover. On all three areas vegetation density is low, particularly in the lower pasture. Changes in species composition were marked by the appearance of such more or less noxious or unpalatable species as mullein, yarrow, Canada thistle, smartweed, nettle and purslane--all frequently associated with land abuse.

In the control plots, established in the cornfield at the time it was abandoned in 1949, the ground cover is nearly complete after only two years. The most abundant species in these two plots are blackberry and wild strawberry. It is obvious in both plots that tree species will soon take over. Numerous stems in both plots exceed 6 feet in height.

In the absence of forest vegetation, stream temperatures increased to the point where they are critical or above the maximum limits for trout. Similarly, stream turbidities were increased by approximtely three times, and siltation or sedimentation increased tremendously.

Edaphic Changes

The results of an infiltration study made in 1949 showed marked differences in the infiltration rates of the portions of the watershed used in different ways. In all the forested plots sampled on the Coweeta area, including the coppice forest portion of the Little Hurricane Watershed, the average infiltration rate invariably exceeded 6 inches per hour. The values noted for the cornfield, upper pasture, and lower pasture respectively in 1949 were 4.00, 3.00 and 0.56 inches per hour. Since many of the storms on the Coweeta area show precipitation intensities in excess of 0.56 inches per hour, high surface runoff rates would be anticipated from the lower pasture. Similar infiltration tests made on the abandoned cornfield immediately before and following grazing in 1950 indicated that even short periods of grazing caused sharp decreases in the infiltration rate.

As indicated by samples collected from an adjacent watershed, the permeability of undisturbed forest soil averaged well over 100 inches per hour in the 0-3 inch layer and over 60 inches per hour in the 3-6 inch zone. Tests on soils collected from the mountain farm area showed minimum values in the lower pasture where the average rates were 6.6 and 2.7 inches per hour for the 0-3 and 3-6 inch layers respectively.

The percent of water-stable aggregates similarly were much higher in the forested areas. In the undisturbed forest the percentages of water stable aggregates over 4 mm. in size in the surface and subsurface layers were 85.5 and 73.8 respectively, compared with percentages of 46.2 and 40.1 in the control plots in the abandoned cornfield. The soil dispersion re-

sulting from the decrease in aggregation is undoubtedly responsible for increases in soil losses from the watershed and indirectly for the increases in surface runoff. An analysis of the aggregation of the fine earth material indicated similar results.

Differences in organic matter content, volume weight, and porosity are also evident. The effect of former cultivation in the abandoned cornfield is evidenced in that the organic matter content of both surface and subsurface layers are nearly the same. In the control plots in the abandoned cornfield the organic content of the subsurface layer is approximately the same as in the cornfield itself. However, the 2 years protection offered the control plots appears to have been sufficient to increase the organic matter content materially in the surface layer. The lowest organic matter content in both layers is noted for the lower pasture. Apparently, grazing has brought about soil compaction and thus inhibited the incorporation of litter and humus. It is probable, too, that earlier cultivation of this area may have caused soil changes in the lower pasture. The coppice forest area showed the highest content of organic matter in both layers. This is probably the result of an accumulation of litter from slash and a heavy herbaceous cover following clear cutting and the decaying of root systems from the trees formerly occupying the area.

The greatest differences in volume weight in both layers were found between the coppice forest and the lower pasture, indicating a close relationship between organic matter content and volume weight. In the surface layer, volume weight values range from 0.82 to 1.11. In the subsurface layer all values are very nearly the same except in the lower pasture where volume weight was 1.28, again showing the effects of trampling. These values, as well as those noted for organic matter content, suggest that the most marked changes in the physical characteristics of the soil occur in the 0-3 inch layer.

In porosity values, a slight decrease in total and noncapillary porosity and an increase in capillary porosity, in comparison with undisturbed forest conditions, is indicated. In noncapillary porosity a decrease of approximately 6 percent by volume is shown. According to many writers, noncapillary porosity determines permeability. From the results of these determinations, small changes in the large pore volume, then, may effect marked changes in permeability rates.

One of the greatest changes in the soil as a consequence of the treatment is in soil losses from the watershed. During the calibration period, 1934-1939, and until August, 1941, the average soil losses amounted to about 154 pounds per acre per year. Following the cutting of the forest and the application of mountain farming practices, the average soil losses increased to well over a ton per acre per year. A small portion of this increase might perhaps be attributed to a change in the method of collecting soil losses. However, virtually all the increase should be assigned to the treatment of the watershed.

Cultivation alone appears to be responsible for marked increases in soil losses. These losses increased sharply for a 2-year period following the cutting of the forest cover in which the cornfield was cultivated and the pasture areas were grazed. During 1944 and 1945 the cornfield was protected and permitted to lie idle while the pastures were being grazed. During

this period, soil losses dropped noticeably. Following this, the cornfield was again cultivated for 4 years and the soil losses mounted to a high in 1949 of over 2-1/2 tons per acre per year. In 1950 and 1951 cultivation was discontinued and the abandoned cornfield was grazed along with the two pasture areas, and again soil losses declined.

Runoff Changes

A study made on the Little Hurricane Watershed indicated an average runoff percent of 2.66 for all storms with a maximum 30-minute precipitation intensity over 0.90 inches per hour for the period in which the area was in forest cover. Following forest cutting and mountain farming, this was increased to 4.50 percent. Summer storms alone gave percentages of 1.53 and 4.79 for the before and after periods, respectively.

A very significant change in the magnitude of flood peaks occurred as a result of the land use treatment applied. Unit summer storms yielding precipitation at the rate of 3 inches per hour for 15 minutes, for example, showed an increase in the resulting maximum flood peak from 27 to 84 cubic feet per second per square mile. At the rate of 5 inches per hour for 15 minutes the increase theoretically would be from 59 c.s.m. to approximately 335 c.s.m.

A study of flood peak frequencies for the watershed indicated similar marked changes. During the period of standarization, only three floods occurred with maximum peaks over 50 c.s.m., while following treatment 25 floods with maximum peaks in excess of 50 c.s.m. were noted. A similar analysis of data from a control watershed actually indicated lower frequency values for the later period.

One of the most significant changes in surface runoff brought about by forest cutting and subsequent mountain farming is the manner in which the runoff water comes off the watershed. Runoff distribution graphs comparing the before and after periods show that the peak runoff occurs about 15 minutes after the beginning of a storm since the area has been treated. Before clearing, the peak runoff did not occur until about 35 minutes after the beginning of a storm. For both periods the duration of runoff was approximately 60 minutes. Prior to treatment approximately 12.5 percent of the storm flow came off the watershed during the peak 3-minute interval. Following treatment, this value jumped to nearly 32 percent.

PRACTICAL IMPLICATIONS FOR LAND USE

As a result of increasing population and economic pressures, thousands of acres of steep forest land within the Southern Appalachian region have been cleared for use as pasture or cropland. The advisability of this practice has been extremely questionable from an agronomic and, particularly, from a hydrologic standpoint. The results of this study show that forest cutting and the application of average to poor farming practices have a very deleterious effect upon the physical properties of the surface soil and increase surface runoff during storms.

Within a short period of time after cultivation is begun, the organic constituent and natural structure of the former forest soil begin to break down, leading to soil dispersion and resultant accelerated erosion. When row crops are cultivated on steep land, the exposed topsoil washes away increasingly with each year and fertility declines until, after a period of a few years, yields have decreased to the point where the operation is no longer profitable.

Since the farmer invested a great deal of labor in the original clearing, he frequently decides to convert the worn-out area to pasture instead of allowing it to return to forest cover.

All too frequently the land now becomes overgrazed, which results in rapid compaction of the already eroded soil due to trampling by the cattle. Infiltration and permeability rates quickly decline, and the soil loses its capacity for water storage. The cumulative effect of these abuses is to increase the volume of surface runoff and to multiply the frequency and magnitude of floods which would have occurred under natural forest conditions.

At first glance, it might appear that the injury is confined to an already worn-out area and thus is of minor consequence. However, once these floods begin to occur in increasing number and magnitude, it becomes clear that the damage is much more extensive and much more serious.

Such flood source areas produce erosion on lower lands which normally would not be subject to serious soil washing. Within the past 10 years many farmers in this region, who depended on the cultivation of row and truck crops in the first bottom lands along the streams for their greatest source of income, have been forced to convert these areas to permanent pasture which can withstand increased flooding.

Results such as these could probably be expected from average to poor farming practices in other areas with similar topography and soils. It might be suggested that better farming methods could alleviate the situation. Corn might be rotated with clover and small grains, and the amount of fertilizer used could be increased to advantage. Less damage from trampling would occur if fences were built and fewer cattle permitted to graze. However, all these improved practices are difficult and expensive on such steep land.

When stream conditions in undisturbed forests are observed, one is convinced that good forests, good soils and good water go hand in hand. Soil conditions under undisturbed forest encourage storage of water and make possible the control of erosion. It is reasonable to believe that through the ages there has developed harmonious adjustment of vegetation, soil and water. This natural adjustment, however, appears to be in delicate balance. It is impossible to disturb the forest without distrubing this equilibrium.

It is oviously impractical, however, to leave all land in forest no matter how excellent the supply of water thus assured would be. Land must be used, but must also be carefully managed in order to husband its potentialities for human satisfaction. As we come to understand all of the physical forces which must be kept in balance, we will be better able to develop land management practices which will permit us to utilize all resources without exploiting any one at the expense of another.

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